S. HRG. 99-595

FUEL CELL RESEARCH, DEVELOPMENT AND COMMERCIALIZATION

HEARING

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON
ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

NINETY-NINTH CONGRESS

SECOND SESSION

ON

S. 1686

A bill entitled the "Renewable Energy/Fuel Cell Systems Integration Act of 1985"

S. 1687

A bill to develop a national policy for the utilization of fuel cell technology

FEBRUARY 24, 1986

Printed for the use of the
Committee on Energy and Natural Resources

U.S. GOVERNMENT PRINTING OFFICE
59-867 O WASHINGTON : 1986

For sale by the Superintendent of Documents, Congressional Sales Office
U.S. Government Printing Office, Washington, DC 20402

S311-38

59-867 O - 86 - 1

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FUEL CELL RESEARCH, DEVELOPMENT AND COMMERCIALIZATION

MONDAY, FEBRUARY 24, 1986

U.S. SENATE,
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The subcommittee met, pursuant to notice, at 10 a.m., in room SD-366, Dirksen Senate Office Building, Hon. Daniel J. Evans presiding.

Present: Senators Evans, Domenici, Hecht, Ford, Bingaman, and Matsunaga.

Also present: K.P. Lau, professional staff member; and Benjamin S. Cooper, professional staff member for the minority.

OPENING STATEMENT OF HON. DANIEL J. EVANS, A U.S. SENATOR FROM THE STATE OF WASHINGTON

Senator EVANS. This hearing will come to order.

This is a hearing of the Research and Development Subcommittee of the Energy and Natural Resources Committee.

I would first like to thank Senator Domenici for having this hearing today. As chairman of the Energy R&D Subcommittee, he has shown great foresight in considering our country's energy R&D future.

I would also like to note Senator Matsunaga's leadership in this field and the fact that he has introduced two bills which are pending before the committee to ease the development, encourage the development of fuel cells. I would also like to thank all of the witnesses on the five panels who are here to testify today, especially since all of you are coming and testifying first thing on a Monday morning.

Fuel cells offer many advantages to energy users. They use a variety of fuel sources, although the focus to date has been on hydrocarbon sources. They are modular in construction and can be easily assembled onsite after the stacks and components have been manufactured at the factory. From an environmental point of view, they are practically noiseless, and they pollute very little, and from the electric utilities viewpoint, they provide a short leadtime for construction and are relatively cheap. Also, they can offer many benefits to commercial and light industrial users in the 40- to 200-kilowatt range.

I had the opportunity to visit 2 weeks ago the Electric Power Research Institute and discuss their work in the fuel cell area with

Dr. Kalhammer, who is with us today. We are really quite close to commercialization of the multimegawatt phosphoric acid units which reflect the hundreds of millions of dollars that the Federal Government and private industry have spent over the past decade. I understand that some electric utilities are seriously considering purchases of such units today.

I believe that this technology should be considered as an integral part of our energy future. As chairman of the Pacific Northwest Electric Power Planning Council for more than 2 years, I directed the drafting of the first 20 year power plan for the Pacific Northwest. An essential part of that plan was the options process which allowed a resource to be developed and brought up for option just prior to the preconstruction phase. I think this sort of options planning needs to be expanded to the rest of the Nation. It seems to me that fuel cell generation provides an ideal resource in such a planning process.

And, frankly, that is why it is so disturbing to me and I think others to see DOE's dramatic cuts in the fuel cell R&D area in the fiscal year 1987 budget. In addition, they have proposed deferrals of $22 million from the fiscal year 1986 budget. It seems to me that we should be doing precisely the opposite for a technology which offers so many advantages. The fuel cell program has been an excellent case study of cooperative cost sharing between groups such as GRI, EPRI, and the Department of Energy. There have been good achievements, yet the Federal Government still has a role, a necessary role in providing support for the high-risk, long-range research and development that the private sector cannot yet execute. I hope that this hearing this morning highlights the achievements and emphasizes the importance of this technology, and gives us direction for the next steps that Congress ought to take.

Before hearing from our first witness do you have any opening remarks Senator Bingaman?

[The texts of S. 1686 and S. 1687 follow:]

II

99TH CONGRESS
1ST SESSION

S. 1686

Entitled the "Renewable Energy/Fuel Cell Systems Integration Act of 1985".

IN THE SENATE OF THE UNITED STATES

SEPTEMBER 20 (legislative day, SEPTEMBER 16), 1985

Mr. MATSUNAGA (for himself, Mr. WEICKER, Mr. HOLLINGS, and Mr. MURKOWSKI) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resource

---

A BILL

Entitled the "Renewable Energy/Fuel Cell Systems Integration Act of 1985".

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Renewable Energy/Fuel Cell Systems Integration Act of 1985".

FINDINGS AND PURPOSE

SEC. 2. (a) The Congress finds that while the Federal Government has invested heavily in fuel cell technology over the past 10 years ($260,000,000 in research and development on fuel cells for electric power production), research on technologies that enable fuel cells to use alternative fuel

sources needs to be undertaken in order to fulfill the conservation promise of fuel cells as an energy source.

(b) The purpose of this Act is to provide funds for research on technologies that will enable fuel cells to use alternative fuel sources.

RESEARCH PROGRAM

SEC. 3. (a) The Secretary of Energy shall implement and carry out a research program for the purpose of—

(1) exploring the operation of fuel cells employing methane gas generated from various forms of biomass;

(2) developing technologies to use renewable energy sources, including wind and solar energy, to produce hydrogen for use in fuel cells; and

(3) determining the technical requirements for employing fuel cells for electric power production as backup spinning reserve components to renewable power systems in rural and isolated areas.

(b) In carrying out the research program authorized in subsection (a), the Secretary of Energy may make grants to, or enter into contracts with, private research laboratories.

REPORT TO CONGRESS

SEC. 4. The Secretary of Energy shall transmit to the Congress on or before September 30, 1987, a comprehensive report on research carried out pursuant to this Act.

AUTHORIZATION

SEC. 5. There are hereby authorized to be appropriated $5,000,000 for fiscal year 1986 to the Secretary of Energy to be used to conduct research as provided in this Act.

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II

99TH CONGRESS
1ST SESSION

S. 1687

To develop a national policy for the utilization of fuel cell technology.

IN THE SENATE OF THE UNITED STATES

SEPTEMBER 20 (legislative day, SEPTEMBER 16), 1985

Mr. MATSUNAGA (for himself, Mr. WEICKER, Mr. HOLLINGS, and Mr. MURKOWSKI) introduced the following bill; which was read twice and referred to the Committee on Environment and Public Works

OCTOBER 18 (legislative day, OCTOBER 15), 1985

Committee discharged; ordered referred to the Committee on Energy and Natural Resources. Once the Energy and Natural Resources Committee reports, the bill be sequentially referred to the Environment and Public Works Committee for thirty calendar days, for the purpose of considering the provision (section 5) addressing EPA guidelines for use of fuel cell technologies. If the Environment and Public Works Committee has not reported, after thirty calendar days, it be automatically discharged and the bill be placed on the calendar

---

A BILL

To develop a national policy for the utilization of fuel cell technology.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Fuel Cells Energy Utilization Act of 1985".

FINDINGS

SEC. 2. The Congress finds that—

(1) while the Federal Government has invested substantially in fuel cell technology through research and development during the past ten years, there is no national policy for acting upon the findings of this research and development; and

(2) if such a national policy were developed, the public investment in fuel cell technology would be realized through reduced dependency on imported oil for energy and the consequent improvement in the international trade accounts of the United States.

ELIGIBILITY FOR EXEMPTIONS UNDER PURPA

SEC. 3. Subsection (j) of section 210 of the Public Utility Regulatory Policies Act of 1978 is amended by—

(1) striking out the comma after "this section" and inserting in lieu thereof a dash;

(2) designating the matter that follows such dash as clause (1);

(3) striking the period at the end of clause (1), as designated by clause (2) of this section, and inserting in lieu thereof "; and"; and

(4) inserting at the end thereof the following:

"(2) the term 'cogeneration facility' in addition to the meaning given such term in the Federal Power Act shall include facilities utilizing fuel cell systems.".

INCLUSION OF FUEL CELLS AS A FUEL CONSERVATION TECHNOLOGY UNDER REIDA

SEC. 4. Section 256 of the Energy Policy and Conservation Act is amended by inserting at the end thereof the following:

"(e) For purposes of this section, the term 'domestic renewable energy industry' shall include industries using fuel cell technology.".

ENVIRONMENTAL PROTECTION AGENCY GUIDELINES FOR USE OF FUEL CELL TECHNOLOGIES

SEC. 5. Within 180 days of the date of enactment of this Act, the Administrator of the Environmental Protection Agency shall prepare Federal guidelines for cities and municipalities specifying environmental and safety standards for the use of fuel cell technology. In the preparation of the guidelines, the Administrator shall utilize the successful experience of the New York City Fire Department in the use of fuel cell technologies.

DEPARTMENT OF COMMERCE INVESTIGATION OF EXPORT MARKET POTENTIAL FOR INTEGRATED FUEL CELL SYSTEMS

SEC. 6. Within 180 days of the date of enactment of this Act, the Secretary of Commerce shall assess and report to Congress concerning the export market potential for integrated systems of fuel cells with renewable power technologies.

○

STATEMENT OF HON. JEFF BINGAMAN, A U.S. SENATOR FROM THE STATE OF NEW MEXICO

Senator BINGAMAN. Well, I have a short opening statement, Mr. Chairman. I want to first of all commend Senator Matsunaga for his leadership in this area of alternative energy resources. He has been at the forefront of making the Senate aware of how important it is for our country to develop alternatives to fossil fuels and in urging the Government to provide the necessary research and development funds to make these alternatives viable in this competitive world market.

I only wish that the administration shared his commitment to our pursuit of research in this area. Today we are discussing one of these alternative technologies, the fuel cell. The fuel cell has the ability to produce electrical energy from a nonpetroleum-based fuel with exceptionally high efficiency, low pollution, and low noise. This technology also has the potential for reducing our dependence on foreign oil, and since NASA's early successes with the fuel cell, the Government has determined that this technology holds promise for the entire country.

Unfortunately, the administration in the past few years has substantially reduced funding for fuel cell research, and once again this year, in fiscal year 1987 budget, their proposal shows a substantial decrease for the fuel cell programs within the Department of Energy. Under the fossil energy and electric energy storage systems functions, fuel cell research is being cut from $35 million to $5 million, and from $17 million to $9 million respectively. These cuts follow the trend of other alternative and renewable energy sources as the Department shifts more and more money to military research.

After reviewing the testimony of some of today's witnesses, I cannot understand how the administration can justify cutbacks in this area. By waivering in our efforts to develop alternative energy sources, we are canceling the Nation's energy insurance policy and quickly losing any competitive advantage we might have in alternative energy technologies.

The President's Commission on Industrial Competitiveness reflects this concern. They said, and I quote:

> Given the limited amount of Federal funds spent on any area of commercial potential, the question of how Government manages its R&D becomes a critical issue. Since Government is the prime funder of basic research, being those areas of risky inquiry that are essential for long term technological preeminence, the competitive consequences of its critical role cannot be overstated.

I look forward to hearing from my distinguished colleague from Hawaii and from the other witnesses this morning.

Thank you, Mr. Chairman.

Senator EVANS. Thank you, Senator Bingaman.

And now we are pleased to have as our first witness our distinguished colleague from the State of Hawaii who, as Senator Bingaman has pointed out, has provided leadership in this area over a long period of time. In fact, I was first attracted to some of the ideas and interests he has had in the field of alternative forms of energy from conversations with him, and I am delighted that, Senator Matsunaga, you are here with us as the first witness.

So please proceed.

STATEMENT OF HON. SPARK M. MATSUNAGA, A U.S. SENATOR FROM THE STATE OF HAWAII

Senator MATSUNAGA. Thank you very much, Mr. Chairman, and I wish first of all to thank you and Senator Domenici for scheduling these hearings and for you conducting these hearings. And I thank you for having cosponsored some of my earlier measures, and I was surprised somewhat that you were not listed as a cosponsor of these two measures. From what you say, I think you are a cosponsor and so——

Senator EVANS. If not, I probably should be, Senator.

Senator MATSUNAGA. Yes; and so would Senator Bingaman, and I thank you both for your remarks.

Senator BINGAMAN. You will probably pick up some allies this morning.

Senator MATSUNAGA. Thank you.

Well, the hearing, as you know, is on S. 1686, the Renewable Energy/Fuel Cell Systems Integration Act and S. 1687, a bill to develop a national policy for the utilization of fuel cell technology. With the cosponsorship of Senators Lowell Weicker, Frank Murkowski, Ernest Hollings, and Dan Inouye, I have introduced these measures not only because of my confirmed belief in fuel cell technology but because I believe that the time is ripe for its commercialization, in and of itself and in tandem with renewable power systems. The current decline in oil prices notwithstanding, Mr. Chairman, there are several compelling reasons why these two bills are both timely and necessary in terms of our national interest.

First of all, the Federal Government has made a heavy investment in the technology of some $260 million over the past 10 years, but it is not yet in a position to benefit from this public expenditure, according to a Congressional Research Service report published last year. This is because the Congress has yet to formulate a strategy for acting on the research findings in fuel cell technology in order to achieve commercialization. I submit, Mr. Chairman, that S. 1686 and S. 1687 would fill this gap.

For a little background, I wish to point out that the goal of Federal research in fuel cells since the mid-1970's has been to develop a highly energy efficient technology with some especially desirable characteristics for electric power planning; namely, low environmental impact, fuel flexibility, high performance, small size, and spinning reserve capability. The primary national payoffs expected from the fuel cell research effort are increased fuel-use efficiency, substitution of alternate fuels for conventional fuels, and development of a potential for improving our national balance of trade.

This latter point is one reason why this legislation is timely now, Mr. Chairman, and I wish to elaborate on it after I have offered a summary of the two bills.

Before doing so, I want to emphasize that the Federal involvement in fostering this technology has been primarily due to congressional initiatives, and the Federal research effort in fuel cells continues to play an important catalytic role in the technology's development.

The first of the two measures, S. 1686, the Renewable Energy Fuel Cell Integration Act, would, among other things, support research on how to use renewable energy sources, including wind and solar, to produce hydrogen for use in fuel cells. In addition, this legislation would support research on the operation of fuel cells which use methane gas generated from various forms of biomass, as well as research on determining the technical requirements for use of fuel cells in electric power production as backup spinning reserve to renewable power systems in rural and isolated areas. This could be a boon to windpower generation in terms of assuring system continuity. The same might be said for photovoltaic systems.

The bill would authorize $5 million for this integrated renewable energy fuel cell research. It would be a small price, indeed, to pay if it should serve to achieve a payoff for the large public investment made to date, and there is good reason to believe it would, if only in terms of an overseas market for this technology.

The second bill, S. 1687, calls for a formulation of a national policy for the use of fuel cells. It would, among other things, amend the Public Utility Regulatory Policies Act, or PURPA, as it is better known, for the purpose of including fuel cell systems under the definition of cogeneration facility. This would have the effect of stimulating the employment of fuel cells on a complementary basis with wind farm operations as well as with other hybrid system cogeneration such as photovoltaics.

This bill would also include fuel cells under the provisions of the Renewable Energy Industry Development Act as a fuel conservation technology in and of itself and when augmented by cogeneration practices. This would permit the Department of Commerce to assess international markets for the technology, identify export barriers, and focus sources of Federal assistance for promoting the export of fuel cells.

Furthermore, the bill would require the Environmental Protection Agency to prepare general guidelines for discretionary use by local governments in authorizing the use of fuel cells. These guidelines would suggest environmental and safety standards which can be drawn from the experience of the New York City Fire Department with this technology during a pilot operation at a Consolidated Edison plant several years ago.

Finally, Mr. Chairman, the bill would require the Commerce Department to survey the export market potential for integrated systems of fuel cells and renewable power technologies, especially in isolated rural settings of developing countries. This I am sure is a most welcome provision in light of our growing national trade deficit.

Mr. Chairman, I may be remiss in not having explained at the outset what a fuel cell is. It is simply a device which converts chemical energy into electricity. It does so by combining hydrogen-rich gas with air and converting the chemical energy of this mixture into electricity directly without any intermediate combustion step. For this reason, it has been hailed as the most efficient electrical generation device in existence. Taking in air, and a liquid, or gaseous hydrocarbon fuel, it turns out direct current, dc electricity

at high conversion efficiency rates, 40 to 60 percent, plus a low amount of waste heat and water with carbon dioxide.

I should add, however, that enough heat is generated to permit cogeneration space heating, for an overall efficiency rate as high as 80 percent.

An interesting point of observation is that while the fuel cell was invented by Sir William Grove as early as 1839, it had its first practical application in the Gemini V flight of August 1985 where it proved to be an efficient, reliable power generator with very high-energy density.

A typical cell produces high direct current in a low voltage. Practical voltages are obtained by connecting many individual cells into what is referred to as cell stack.

Besides their high efficiencies, fuel cells offer a number of advantages, including economy and size. They can be factory assembled, leading to short construction leadtimes. Put on line in comparatively short periods, the capital outlay and interest costs can be expected to compare favorably. Output can be increased modularly as demand rises. Their compact design means small, discrete increments of capacity, allowing a better match of capacity to anticipated growth. While all these advantages appeal to utilities, there are also pluses for those interested in decentralized systems. I understand witnesses will testify this morning on the role in electric hybrid vehicle development as well.

Representing a State consisting of eight separate islands, I am especially intrigued by the possibilities of fuel cell hybrid systems. Where hydrogen storage is feasible, renewable power sources could drive an electrolysis process to produce hydrogen during offpeak periods that can be used to operate fuel cells during peak demands. This is especially significant when viewing fuel cell spinning reserve advantages and the prospects for exporting the technology to Third World markets.

If off-peak power from renewable sources is used to produce hydrogen for operation of fuel cell stacks during peak periods, the fuel cell's spinning reserve and load-following capabilities would be enhanced. For example, photovoltaic systems reach their peak output in the early afternoon, but utility peakloads usually occur during the early evening. The combined output of these complementary facilities may enable them jointly to defer or displace some conventional powerplant construction before the turn of the century.

For the reasons I have stated, Mr. Chairman and members of the subcommittee, we need to give fuel cell technology explicit recognition under PURPA as a cogeneration technology, and we need to encourage hydrogen production from renewable sources expressly for fuel cell use.

I urge your favorable report on S. 1686 and S. 1687 to expedite the advancement of fuel cell technology, and I wish again to express my appreciation to the chairman for scheduling this hearing.

I thank you very much.

Senator EVANS. Thank you very much, Senator Matsunaga, and before we get into a round of questioning, I would ask, Senator Hecht, do you have any initial remarks?

Senator HECHT. Thank you, Mr. Chairman. Just to say, Sparky, I was quite impressed with that. That was terrific.

Senator MATSUNAGA. Thank you.

I will see you later about becoming a cosponsor of the bills. [Laughter.]

Senator EVANS. We have been joined by our chairman.

I am delighted, as I have indicated at the beginning of the hearing, that Senator Domenici has scheduled this series of hearings which I believe are terribly important if we are going to put together an appropriate, comprehensive, and well-designed energy research package for the country.

And Senator Domenici, do you have some initial remarks?

STATEMENT OF HON. PETE V. DOMENICI, A U.S. SENATOR FROM THE STATE OF NEW MEXICO

Senator DOMENICI. Well, Senator Evans, let me just say I had a brief statement. I will put it in the record, and thank you for agreeing to Chair the subcommittee's hearings.

I will be unable to be here for more than another 10 minutes, but I agree with you that these are important hearings. I hope as we proceed through with the witnesses that eventually we will get some indication as to the cost efficiency of this program and its ultimate utilization.

While I understand that cost efficiency may not be the whole situation with reference to remote area needs which these kinds of cells, combined with other systems, might serve to alleviate some real problems in the world, I am presently as concerned as you are, Senator Evans, about many of the alternate approaches going down the drain with the precipitous fall in oil prices which would cause us to assume that nothing ought to be done because they can't compete in the next 4 or 5 years. I'm not so sure that that ought to be the sole test at this point.

Obviously this kind of direct generation has some great potential, and Senator Matsunaga, I compliment you for your leadership, and I wish I could hear all the witnesses, but obviously we will attempt to bring the matter to the full committee when we have completed the hearings. It will be a very difficult year for the Energy Committee because of the tremendous state of flux. You are fully aware of that. As a solar advocate, you know what is happening because the finance committees in the two bodies have not been able to extend the credits. A decade of work may go down the drain here rather rapidly. I, for one, do not think that we ought to let that happen, but it appears that it is happening. That does have some bearing on whether Congress would want to put more money into these kind of systems.

I repeat, I think within reasonable bounds we ought to, and we ought to move ahead and try to maintain our lead in this technology.

Thank you very much for your leadership.

[The prepared statement of Senator Domenici and a statement from Senator Weicker follows:]

STATEMENT OF SENATOR DOMENICI

Good morning ladies and gentlemen. I would like to call the meeting to order. Today we are receiving testimony on Fuel Cells programs and S.1686, "The Renewable Energy/Fuel Cell Systems Integration Act" and S.1687, "The Fuel Cells Energy Utilization Act."

Over the past decade, Congress has appropriated nearly $300 million in research and development on fuel cells for electric power production and transportation in DOE alone. Fuel cells hold the promise of high efficiency, low environmental impact, fuel flexibility, and compact in size. Today, we will probe the status of fuel cells technologies, the adequacy of R&D needs, the coordination efforts among all interested groups, the cost-benefits of ongoing programs, the practical and potential applications and the commercial potentials.

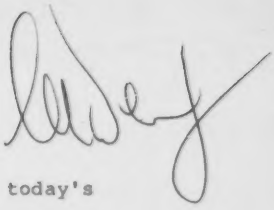
Today, We have Sen. Matsunaga, who has shown great interests in this technology, Department of Energy, private funding organizations, users groups, manufacturers, researchers, and technology assessing groups. Regretably, due to the current circumstances NASA would not be here today. NASA should be credited with the first successful application of this promising technology. They have agreed to present written testimony, however. There are a few other organizations, such as IFC and the Army, who are unable to be here and would contribute to this hearing.

With this brief introduction, let us get on with the hearing.

STATEMENT BY SENATOR WEICKER

ON S. 1686 - S. 1687

FEBRUARY 24, 1986



Though prior commitments preclude my attendance at today's hearing on legislation aimed at fostering the development and use of renewable energy fuel cell technology, I did want to indicate my support for this effort and urge continued coordination between the public and private sectors so that we may realize the potential of this new technology.

As was concluded by a recent study of the Congressional Research Service (CRS), the shift from developmental activities into commercialization of this technology can only be made within the framework of a clear, steady and forward-looking national policy. The Federal government has invested heavily over the last ten years in fuel cell research and development. Without this investment we might not be on the threshold of a major breakthrough in alternative energy technology. Unfortunately, the advancements that have been made may not be realized if a coherent national policy for completing the development phase and moving the technology into the domestic and international marketplace is not crafted.

It is with this in mind that I joined, as an original co-sponsor, my colleague Senator Matsunaga in offering two measures, S. 1686 and S. 1687, directed at establishment of a national fuel cell policy which encourages integration with renewable energy sources, and amends existing statutes to include fuel cells among

those technologies extended access to and promotion in foreign markets.

It is entirely reasonable to expect, Mr. Chairman, that by the early 1990's direct fuel cell powerplants will be introduced in the marketplace as a dispersed generation capability in the 2 to 15 MW size range. With its high efficiency ratings, the direct fuel cell will be ideally suited for the incremental additions to capacity that most utility growth projections now contemplate in lieu of far more expensive new central station powerplants.

As bright as the prospects for fuel cell technology are, its emergence as a viable alternative to more conventional systems and its attractiveness in the marketplace is not possible without some level of Federal support. I fear that the virtual abandonement of the program the Administration has proposed in its FY87 budget request and its spending deferrals for FY86 may well inhibit both continued private sector R&D support and the desired commitment by utilities for future utilization. Therefore, Mr. Chairman, I urge adoption of the Matsunaga measures to serve as our guide in forging ahead with adequate Federal support for this technology that now lies on the near horizon.

I commend you for conducting these hearings and placing the Subcommittee at the forefront of policy formulation on our nation's future power generation needs. I look forward to working closely with you on these matters of mutual concern in the months ahead.

Senator MATSUNAGA. Thank you, Mr. Chairman, for your kind words.

Senator EVANS. Now, Senator Bingaman, do you have any questions of Senator Matsunaga?

Senator BINGAMAN. I would just ask Senator Matsunaga if he had any comment on this proposed deferral? I gather there is a proposal by the administration to defer the spending of $22 million of the $35 million that Congress appropriated in 1986 for this research and development. Perhaps that is something you would want to comment on.

Senator MATSUNAGA. I wholeheartedly agree with the comments made earlier by Senator Evans in that regard, and in the interests of time, I would suggest that I simply restate what Senator Evans had said.

And if I may make a suggestion here, because I do not claim to be expert in the technicalities of this matter, and there are many witnesses scheduled for today, I would gladly just terminate my testimony this morning, and if the chairman will invite me, I will sit and listen along with the members of the subcommittee.

Senator DOMENICI. You are welcome.

Senator EVANS. We certainly do invite you, and we are delighted to not only have you here to testify, but also to listen and to question the other witnesses as they do come along.

Senator MATSUNAGA. Thank you very much.

Senator EVANS. With that, our next witness is Robert San Martin, Deputy Assistant Secretary for Renewable Energy, U.S. Department of Energy, accompanied by Richard Harrington, Deputy Assistant for Coal Utilization, Advance Conversion, and Gasification.

Gentlemen, we are delighted to have you, and will you proceed.

STATEMENT OF DR. ROBERT L. SAN MARTIN, DEPUTY ASSISTANT SECRETARY FOR RENEWABLE ENERGY, OFFICE OF CONSERVATION AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY, ACCOMPANIED BY RICHARD E. HARRINGTON, DEPUTY ASSISTANT SECRETARY FOR COAL UTILIZATION, ADVANCED CONVERSION, AND GASIFICATION, OFFICE OF FOSSIL ENERGY, DEPARTMENT OF ENERGY

Dr. SAN MARTIN. Mr. Chairman, members of the committee, thank you for the opportunity to appear before you today to discuss the Department of Energy's fuel cell technology program.

As you mentioned, Mr. Chairman, two organizational components of the Department of Energy are represented today, the Renewable Energy Office and the Fossil Energy Office. Both of our organizations have ongoing complementary research programs to develop fuel cell technology.

Mr. Chairman, I have prepared a statement for record, and with the committee's consent, I am prepared to summarize some of our comments.

Senator EVANS. Your full statement will be in the record, and please proceed.

Dr. SAN MARTIN. Thank you, Mr. Chairman.

The fuel cell development activities of modern times can trace its origins back to work that began more than 2 decades ago in laboratories and special applications research areas. Today this effort has evolved into a multifaceted research program. The Office of Fossil Energy currently oversees research on various types of fuel cells, including molten carbonate, solid oxide fuel cells, and phosphoric acid. These are predominantly suited for stationary utility and large customer side of the meter types of applications.

The renewable energy group manages research on solid polymer electrolyte fuel cells, also known as proton exchange membrane fuel cells. The future application for this technology will be predominantly for mobile vehicle applications.

This multipronged research effort is well coordinated, with both elements of the Department exchanging results and future plans on a regular basis.

Fuel cell technology, we believe, may be a promising energy supplier with attractive energy conversion efficiencies, environmental potential, provided that we are successful in overcoming several of the barriers that now exist in the development of this technology. Currently available fuel cells use hydrogen as a fuel which can be derived from a number of hydrocarbon sources. As a result, the fuel cells are in fact fuel flexible. They have demonstrated to be capable of operating on methane gas generated from a variety of sources, for example. The multifuel capability is one of the inherent advantages.

Therefore, rather than demonstrating multiple sources of clean fuels, the Department of Energy has focused its program on cell and stack development and on developing improved methods for cleaning fuels that are inherently dirtier than natural gas to make them acceptable candidates for fuel cell applications. Once alternative fuels have been cleaned, switching fuels is a relatively low risk decision.

In support of the Conservation and Renewable Energy Office, Los Alamos National Laboratory has been conducting an integrated research and exploratory development program on the proton exchange membrane fuel cells for vehicle applications. The objective is to make this fuel cell technology viable and take it from its present status as a laboratory device to a proof of concept level, establishing it as a practical alternative to the internal combustion engine for vehicular propulsion.

Mr. chairman, this has been the focus of the activities that have been undertaken by the Renewable Energy Office in pursuit of fuel cell development. I would like to ask my colleague, Dick Harrington, if he would please give you a very brief overview of the work being undertaken by the Office of Fossil Energy in this regard.

[The prepared statement of Dr. San Martin follows:]

Joint Statement Of

Robert L. San Martin
Deputy Assistant Secretary
for Renewable Energy,
Office of Conservation and
Renewable Energy

and

Richard E. Harrington
Deputy Assistant Secretary
for Coal Utilization, Advanced,
Conversion, and Gasification
Office of Fossil Energy

U.S. Department of Energy

to the

Committee on Energy and Natural Resources
Subcommittee on Energy Research and Development
U.S. Senate

February 24, 1986

Mr. Chairman and Members of the Committee:

Thank you for the opportunity to appear before you today to discuss the Department of Energy's fuel cell technology program and the two Senate bills relating to fuel cells, namely S. 1686 and S. 1687. Two organizational components of the Department of Energy are represented here today -- the Renewable Energy office and the Fossil Energy office. Both have ongoing, complementary research programs to develop fuel cell technology.

OVERVIEW

The DOE fuel cell program can trace its origins to work that began more than two decades ago in laboratory and special application research. Today this effort has evolved into a multi-faceted research program. The Office of Fossil Energy currently oversees research on Phosphoric Acid, Molten Carbonate, and Solid Oxide fuel cells. These are predominantly suited for stationary, utility, and large customer-side-of-the-meter application. The Renewable Energy group manages research on Solid Polymer Electrolyte fuel cells -- also known as Proton Exchange Membrane (PEM) fuel cells. The future application for this technology will be predominantly for mobile vehicle application.

This multi-pronged research effort is well coordinated, with both elements of the Department exchanging results and future plans on a regular basis.

Technology Description

Fuel cells are energy conversion devices that convert chemical energy directly into electrical energy without the inherent efficiency limits of heat engine cycles. A complete fuel cell power plant would typically include a fuel processing section (such as a reformer or a coal gasifier section with gas cleanup), the power producing section (often referred to as the fuel cell stack), and a power processing section with a direct current-to-alternating current inverter.

Fuel cells are powered by the electrochemical combination of hydrogen and oxygen. The source of hydrogen can vary considerably; virtually any hydrocarbon fuel can be a potential feedstock for a fuel cell power plant although for economic reasons, natural gas (methane) and coal will likely be the principal fuels. With low temperature (400 degree F) phosphoric acid fuel cells, the fuel must be processed in a reformer to produce a hydrogen-rich gas for the cell stack. Provisions are necessary to remove the odorants (sulfur compounds) which are mixed with the methane in natural gas to provide warnings of gas leakage. These sulfur compounds and other contaminants can degrade fuel cell and reformer performance unless reduced to low levels.

Other hydrocarbon fuels such as alcohols and petroleum distillates can be used in a similar manner as long as the reformer and fuel cell are protected from too high a level of contaminants.

More advanced fuel cell concepts -- specifically, the molten carbonate and solid oxide fuels cells -- offer the potential of streamlining the reforming process. The high cell operating temperature (approximately 1200 degrees F for molten carbonate fuel cells and approximately 1800 degrees F for solid oxide cells) has the potential to reform the natural gas directly within the fuel cell. Again, control of contaminants is required.

Higher operating temperatures may provide significant efficiency and capital cost advantages, however, elevated temperatures are not suitable for all potential fuel cell applications. In particular, the choice of a fuel cell for some mobile application may be dictated, in large part, by the need for a system capable of operating at reduced temperatures, i.e., the phosphoric acid or proton-exchange-membrane technology. Other concepts in the very early development phases (such as the monolith solid-oxide concept) may offer low weight and low volume systems compatible with some mobile applications.

Application of the Technology

The phosphoric acid fuel cell technology has been well proven but remains to be adopted commercially. The obstacles confronting phosphoric acid fuel cell applications are primarily economic in nature. The capital cost of the fuel cells is currently several times greater than alternatives such as gas turbines or conventional pulverized coal fueled steam generators. While mass production may make phosphoric acid fuel cells more competitive, industry must be prepared to address production and marketing issues before the technology will see widespread commercial application. It is possible that fuel cell technology will be applied initially in specific market niches and subsequently, evolve naturally into broader commercial use.

Fuel cell powerplants are expected to see their earliest applications in the electric utility power generation sector. Initial entry would be by plants using natural gas or distillate fuels and providing primarily peaking power or cycling power generation. Fuel cell plants operating on coal are expected to expand the potential market to baseload power generation applications.

A second area of fuel cell application is the residential and commercial sector. Strong interest by the gas utilities is evidenced by the ongoing field test of nearly fifty 40-kilowatt power plants producing electricity and cogenerated heat. Introduction of commercial gas-using fuel cells in this sector is also expected in the late 1980s. Due to the smaller size of fuel cell power plants in the residential and commercial sectors, direct integration of a fuel cell with a feedstock supplier (e.g., a coal gasifier) seems unlikely. Use of feedstocks such as coal or biomass in these applications will likely depend upon the economic competitiveness of processes to convert these fuels into pumpable gaseous or liquid products and the existance of suitable delivery systems.

Fuel cell use in the industrial sector could follow introduction in the electric utility sector and basically rely on modules similar to those being developed for electric utility plants. Fuel cell use in the transportation sector will depend upon the success of ongoing research efforts to overcome constraints on cost, size, and operating conditions.

Involvement with Domestic/International Groups

In addition to coordination among the two major fuel cell programs within the Energy Department, we participate in the National Fuel Cell Coordinating Group. Other members of this national program are the Electric Power Research Institute (with an electric utility interest), the Gas Research Institute (representing the gas utility industry), the National Aeronautics and Space Administration, the Department of Defense, and numerous private corporations involved in the development of fuel cells.

International interest and involvement is also helping to shape the future of fuel cells. Recently, for example, the International Fuel Cell (IFC) Corporation, jointly owned by United Technology Corporation and Toshiba of Japan, has been formed.

The Refocused Federal Program

In recent years, research interest within the Department has begun to shift from technology that is nearing commercial applications -- that is, the Phosphoric Acid fuel cell -- to more efficient, but less developed technologies, such as the Molten Carbonate, Solid Oxide and Solid Polymer Electrolyte. This is consistent with the Administration's policy of targeting taxpayer dollars toward those research efforts which remain beyond the scope of private research and development. An investment of more than $200 million by the Energy Department and more than $360 million by the private sector has brought the Phosphoric Acid technology to a sufficient maturity level such that the private sector can now assume full responsibility, as IFC has begun to, for the remaining development and commercialization of this technology.

In attachments to this testimony, we have provided more detailed descriptions of the ongoing fuel cell efforts within the Energy Department. These sections of our statement provide more definitive explanations of the cost-benefits of the fuel cell program, the practical and potential applications of fuel cells, and their commercialization potential.

Suffice it to say in this overview that fuel cell technology may be a promising energy supplier with attractive energy conversion efficiencies and environmental potential, provided the economic barriers that now exist can be overcome. Currently available fuel cells use hydrogen as a fuel which can be derived from a number of hydrocarbon sources. As a result, fuel cells are fuel flexible; they have been demonstrated to be capable of operating on methane gas generated from a variety of sources. The multifuel capability is one of the inherent advantages of fuel cells. Therefore, rather than demonstrating multiple sources of clean fuels, DOE has focused its program on cell and stack development and on developing improved methods for cleaning fuels that are inherently "dirtier" than natural gas to make them acceptable candidates for fuel cell applications. Once alternative fuels (e.g., fuels other than pipeline gas) have been cleaned, switching fuels is a relatively low risk commercial decision.

The technology is in hand to power a fuel cell using properly cleaned coal gas, landfill gas, methanol, natural gas and hydrogen. The use of fuels from biomass does not represent a major technical obstacle, but is more dependent upon competitive economics, the local fuel supply infrastructure, and uncertainties regarding capital costs and long-term durability.

S. 1686 & S.1687

Let me turn now to specific comments on the two Senate bills:

As indicated in both the overview and in subsequent program descriptions, substantial progress has been made in bringing fuel cell technology to its present state. The Phosphoric Acid technology, in particular, now stands ready for the private sector to commercialize -- its technical potential has been proven both for utility and smaller-scale, "onsite" applications.

In light of the technical maturity achieved by today's first-generation fuel cells, we must conclude that neither S. 1686 nor S. 1687 is required to meet the objectives of stimulating fuel cell research and applications. Particularly in a time of tight budgets, we believe taxpayer dollars are more appropriately spent on longer-range, more generic research that will benefit all types of fuel cells, rather than on perfecting technologies that are within the commercial scope of the private sector.

We have much the same reaction to the specific cogeneration provisions of S. 1687. While recognizing that the ultimate objectives of the bill are sound, we question whether it is necessary to accomplish its stated goal. The phosphoric acid fuel cell has been demonstrated at several sites across the country to be capable of generating both onsite electric power as well as usable thermal energy. The molten carbonate and solid oxide fuel cells, still currently in less mature stages of development, may be substantially better candidates for cogeneration application since they operate at much higher temperatures.

Clearly, where government can provide the most effective contribution to fuel cell technology is in building a solid base of technological information which industry can use to make market-oriented, developmental decisions.

Our current fuel cell program, particularly as it is presented within the President's Fiscal Year 1987 budget request, has been carefully fashioned to ensure that tax dollars are not supplanting private sector funding. We will continue to make available to the private sector the results of our technology-base research and we will encourage them to implement this research when market forces dictate.

The Department of Energy is committed to expanding the range of technical options available to the private sector that will improve our Nation's energy future; fuel cells are a sound prospect for this future. As I indicated previously, the remaining pages of our testimony provide more details on the ongoing fuel cell efforts within the Department of Energy.

Thank you for the opportunity to discuss this area of research with you today.

ATTACHMENT 1

THE FOSSIL ENERGY FUEL CELL PROGRAM

The Office of Fossil Energy has a fuel cell systems program with the following goals:

- o Develop systems using natural gas and distillate fuels as an interim step toward developing coal-based fuel cell power plants;
- o In the long-term, develop advanced systems that use coal as a primary energy form.

The Fossil Energy program is participating with the private sector in developing fuel cell power plant technologies for electric utility, industrial and "on-site" applications that produce electric and thermal energy at the user's location.

In addition to these development activities, assessments are being performed to identify potential applications of fuel cells to new markets.

Currently, the Fossil Energy program is supporting the development of three types of fuel cells (characterized by the cell electrolyte used): phosphoric acid, molten carbonate, and solid oxide. The federal role is principally to support the development of fuel cell stack technology; the private sector is developing the balance of plant subsystems and will undertake future market-related activities.

The Fossil Energy fuel cell program is currently directed towards multi-megawatt electric utility power plants and multi-kilowatt on-site power plants for commercial and industrial applications. In some uses, first generation phosphoric acid systems offer attractive benefits, however, more advanced fuel cell technologies -- the molten carbonate and solid oxide systems -- are expected to offer additional benefits in terms of economics, technical performance and fuel flexibility. Compared to phosphoric acid systems, the advanced fuel cell technologies are expected to be more amenable

to integration with a coal gasifier. The rationale for development of multiple advanced technologies is that, at the present embryonic state of development of these advanced concepts, it is uncertain which technology will be able to progress satisfactorily to the point of a commercial prototype power plant, the development stage already achieved by phosphoric acid systems.

Phosphoric Acid Fuel Cells

Phosphoric acid systems are the most mature of the fuel cell systems under development by DOE and have the greatest private sector cost-sharing. Phosphoric acid systems have been under development since the 1950s by the private sector, and since 1976, by DOE (formerly ERDA). Over that period of time, DOE has expended $200M and the private sector over $360M, for research on phosphoric acid fuel cells. There has been a strong and continuing interest in phosphoric acid systems (and advanced systems) by the electric and gas utilities.

Within the phosphoric acid program, two fuel cell applications are being pursued -- electric utility systems and on-site integrated energy systems. The primary difference between the two applications is fuel cell unit size, with the electric utility systems being in the multi-MW range and the on-site systems in the 40 kW to 400 kW range. Parallel design approaches are being pursued in each of these areas. The phosphoric acid fuel cells being developed in one effort use a water cooling loop for cooling of the fuel cell section. This is the technology used in a 4.8 MW preprototype electric utility power plant designed to operate on natural gas or petroleum distillate in a joint project with EPRI and Consolidated Edison. This technology was also used in a year long field test of forty-six 40 kW on-site/integrated energy systems in a joint project with the Gas Research Institute involving test sites in 22 states and participation of nearly 40 utilities.

As of January 1986, the 40 kW field test program has logged a cumulative total of over 266,000 hours of operation. Although many of the units have completed testing, 26 powerplants were still being tested as of the end of 1985. Among the units still being tested are two powerplants that are already using alternate fuels. Southern California Edison is operating one of these fuel cell powerplants on landfill gas using a modified off-the-shelf gas cleanup system. Southern Company Services operates their unit on coal bed methane in Muscle Shoals, Alabama. The Southern California Edison unit has accumulated over 4400 hours and the Southern Company Services powerplant has operated over 7500 hours of the total 8000 hours planned for each unit in the field test program. Both powerplants have the capability of switching from pipeline natural gas to the alternate fuel with no degradation of performance observed.

This field test is presently being completed under the management of GRI. Further advancement of cell and stack technology is expected to lower plant costs and improve the performance of plant subsystems. Such advancements are currently being developed and evaluated for incorporation into an 11 MW electric utility power plant design and into a 200 kW on-site system.

An alternative phosphoric acid systems approach for electric utility power plants uses gas-loop cooling of the fuel cell section. Performance goals have been demonstrated in 9 and 10 cell, gas-cooled stacks for two to three thousand hours (goal is 40,000 hours) and scaleup to 25 and 100 kW stacks has been started. The developer, Westinghouse, is designing a 7.5 MW system which would utilize multiples of the 100 kW stacks.

An alternate phosphoric acid system is also under development for on-site cogeneration application. This system uses a dielectric fluid for stack cooling. A 25 kW stack has been tested and a second is being made

ready for tests. The developer, Engelhard, plans to use multiples of these 25 kW stacks in on-site systems of 25 to 100 kW.

Private sector commercialization of first generation technology (i.e., phosphoric acid system) is expected to aid in establishing a viable fuel cell industry that can assume responsibility for developing improved fuel cell types in the course of typical product improvement.

Molten Carbonate Fuel Cells

Molten carbonate fuel cell technology is at an earlier stage of development than the phosphoric acid fuel cell. The molten carbonate fuel cell program was initiated in 1976. A series of exploratory development projects focused on verifying feasibility and identifying technology development needs. This resulted in a major effort beginning in 1979 to develop the technology to permit large scale molten carbonate systems to operate on coal.

Cell performance goals have been demonstrated in short term tests with clean gas. A two thousand hour test of a subscale stack (20 cell, 1 square foot each) has demonstrated adequate solution of the electrolyte management problem which had been present in earlier molten carbonate stacks. Current efforts focus on improving the life of cell components within cost constraints and on scaling-up to full size stack components.

The concept to improve performance through internal fuel reforming of natural gas or other sources of methane is also being developed. This concept has been demonstrated in cells and a small stack but has not yet been incorporated into large stacks or tested for long duration.

Solid Oxide Fuel Cells

Solid oxide fuel cell technology is in the earliest stages of development. These fuel cells operate at high temperature (approximately 1800°F), thereby

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offering high-quality co-product heat for cogeneration or for use in a bottoming cycle for increased efficiency. In addition, they offer the potential for using simple fuel processing systems because carbon monoxide in the fuel gas does not have to be converted with steam to hydrogen and carbon dioxide (as in phosphoric acid systems), and CO_2 recycle is not required (as in the molten carbonate systems). Internal reforming is readily achieved as a result of the high operating temperature, and solid oxide cells have a lower sensitivity to sulfur impurities.

The current DOE effort, initiated in 1980, is aimed at producing a practical cell design and fabricating and testing a 5 kW generator in 1986, operating on coal gas. Submodules which would form parts of the 5 kW generator have been tested for several thousand hours and substantial progress has been made in fabricating these cells and submodules. Upon successfully testing the 5 kW generator, it is planned to design and test a 100 kW module to verify the technical feasibility of the solid oxide fuel cell for utility power generation from coal gas.

ATTACHMENT 2

RENEWABLE ENERGY RESEARCH

1. Background

With funding from the Office of Energy Storage and Distribution (OESD), the Electronics Division at Los Alamos National Laboratory is conducting an integrated research and exploratory development program on proton exchange membrane (PEM) fuel cells for small vehicle applications. The objective is to take this fuel cell technology from its present status as a laboratory device to a proof-of-concept level, establishing a practical alternative to internal combustion engines (ICE) for vehicular propulsion. The research is aimed at developing technology with range and performance equivalent to an ICE, high efficiency, ability to use a nonpetroleum fuel (methanol), and low air and noise pollution. A system study, carried out at Los Alamos National Laboratory, indicates that a fuel-cell-powered vehicle using methanol can travel approximately twice as many miles as an ICE using gasoline. The by-products of a methanol-powered fuel cell are almost entirely water and carbon dioxide which would make fuel cell propulsion particularly attractive for urban applications.

To realize the potential of transportation fuel cells, the power density must be increased from 2.8 kW/meter^2 to 7.0 kW/meter^2, the cost must be reduced from $300/kW to $50/kW, and the transient performance and startup characteristics of the system must be improved from 7 to 10 minutes to a minute or less. The key areas under investigation in the DOE/

OESD effort are, therefore: (1) developing an understanding of electrocatalysis and of new, improved electrocatalysts; (2) developing an understanding of ion and water molecule transport in membranes and use of this understanding to design an improved and cheaper membrane; and (3) an understanding of the catalytic conversion of methanol to hydrogen and carbon dioxide (reforming) in order to design and fabricate a fuel processor capable of meeting the necessary transient behavior for vehicular applications.

In support of these key areas, single cell testing of PEM fuel cells to determine performance, operational parameters, and possible unique failure modes under vehicular operational regimes is being carried out. In addition, a 20-kW state-of-the-art methanol reformer/phosphoric acid fuel cell has been tested to provide baseline performance data.

At a workshop held at Los Alamos in August 1977, at which automotive companies and fuel cell research and development companies were represented, methanol was selected as the fuel of choice for fuel-cell-powered vehicles. As a liquid fuel, methanol would enable much of the existing industrial plant and distribution system to be maintained. Moreover, methanol can be synthesized from natural gas, coal, biomass, and other sources. For a fuel cell, methanol is a means of storing hydrogen at high density. A process called reforming, by which hydrogen is produced, is therefore an important facet of the research. Of all the hydrocarbon-based fuels, methanol is reformed at the lowest temperature, 200-250°C. Carbon dioxide, a by-product of reforming, is compatible with fuel cells based upon acid electrolytes, because carbonates are precipitated in aqueous alkaline electrolytes and blocks gas transport within the cell.

Low temperature fuel cells operating on reformed methanol are, therefore, restricted to acid electrolytes.

A second factor that determines the choice of fuel cell for mobile application is operating temperature. In such a system with frequent cycling, the lower the operating temperature, the better. In our view, this restricts the choice to phosphoric acid and PEM fuel cells. The phosphoric acid fuel cell, which operates at 200°C, is the most highly developed at the present time, while the PEM cell operates below 100°C. Since there is no need for high quality cogenerated heat in a vehicle, the low temperature is not a penalty as it would be in stationery applications.

By the end of FY 1984, Los Alamos was focused on the PEM fuel cell system due to its advantages of lower operating temperature and higher power density.

The major thrust areas; electrocatalysis, PEM structure and transport, and reformer chemistry will now be described:

Electrocatalysis

In a fuel cell, the activity and cost of the catalysts are dominant factors in the design. Even small improvements in the activity of the cathode catalyst (tens of milivolts increase in cell voltage) can result in significant improvements in efficiency and major improvements in power density, both of which are very important for vehicular applications.

Accordingly, a substantial part of the current research at Los Alamos addresses the catalyst problem. This work ranges from fundamental theoretical and experimental studies to the characteristics of, and life tests of promising catalysts.

Membrane Structure, Transport, and Interface Studies

PEM fuel cells are based on a fluorocarbon polymer membrane that exhibits facile proton conduction. Most current cells are based on a commercial polymer which consists of long teflon-like polymer chains with sulfonic acid side groups. To conduct protons, the membrane must contain significant amounts of water. Improved fuel cell design will require optimizing the ion transport, managing the water transport, improving the electrode contact, and reducing the cost of these membranes.

The effort to understand both ion and water transport phenomena is being attacked by both experimental and modeling efforts. A working model for the membrane structure has been developed. It is speculated that the polymer molecule takes on a helical configuration allowing an interaction between the sulfonic acid side groups to form water-filled ionic clusters. Such clusters are inferred from x-ray data and are a critical element in most models of ion transport through the membrane. Using this configuration as a basis, both continuum and molecular dynamic calculations of transport through the membrane have been conducted.

Understanding the factors affecting water flow through PEMs is critical for modeling and designing membranes and maintaining water balance

in operating fuel cells. Data were determined for water flow through membrane samples. Results showed that flow rates depend directly on the hydrated ion size. This offers confirmation of the hypothesis that the transport channels result from the competition between ionic repulsion forces and the stress from the polymer backbone.

A critical factor determining PEM fuel cell performance is the electrode catalyst-membrane interface where the chemical reactions take place. Complex impedance spectroscopy is being used to determine the steps in the reactions. Measurements of carbon monoxide poisoning on smooth platinum hydrogen electrodes were also made with this technique. It was also observed that carbon monoxide poisoning persisted even 15 hours after flushing with pure hydrogen. On conventional PEM electrodes, 1% carbon monoxide reduced the current density at room temperature by about two orders of magnitude.

Perhaps the most significant achievement this year was the demonstration that the catalyst loading in a PEM fuel cell can be dramatically reduced by pretreating commercially available (Prototech) electrodes with the polymer. The electrodes were painted with a thin layer of a solution of the polymer and then air dried. Although these electrodes contain about an order of magnitude less platinum than the conventional PEM electrodes, at moderate temperatures their performance is comparable for both anode and cathode reactions. This is an important advance since the cost of platinum has been the major cost in PEM fuel cells. Further work on these electrodes will be focused on higher temperature operation where

control of the hydration of the membrane in both the electrolyte and the electrode structure is more difficult.

Evaluation is continuing of commercially available membranes that retain performance levels while offering a cost reduction from the membrane now used. This approach is combined with the catalyst loading reduction mentioned earlier. To date a membrane has been identified with acceptable performance at about half the cost of the presently used membrane.

Reformer Investigations

Results to date have shown that the reformer is one of the most critical components in attaining a viable vehicular power plant. The methanol reformer must be able to meet transit requirements and still maintain minimum carbon monoxide levels. Present designs are not capable of doing this. A thorough understanding of the reforming reaction is necessary to attain satisfactory reaction rates at adequate space velocities with minimal or no carbon monoxide production. Heat and mass transfer within the reformer system also must be well understood. Efforts are pursuing both experimental and modeling approaches to gain an understanding of reforming and to reach a point where a reformer can be designed and fabricated that can meet the transient and fuel quality requirements.

Future Research and Development Plan

The research of the past several years has increased our confidence that PEM-based fuel cells are the most promising technology for widespread use in the transportation sector. They offer the potential for higher power density, better startup characteristic, higher reliability, and lower cost than other fuel cell types that can operate with methanol-derived fuel in a vehicular application. A high power density, low cost PEM technology will also find many other applications particularly where compact or mobile electric power is required. Many of these virtues derive from the lower operating temperature of PEM fuel cells. Low operating temperature facilitates startup, minimizes material corrosion, and allows cheaper plastic and extrudable components to be used. The solid electrolyte also simplifies the design and sealing of the cells. However, the high quality heat that is cogenerated by high temperature installations increases the efficiency in stationery applications.

Problems remain to be solved. These include increasing the power density to levels that can compete with internal combustion engines; reducing the fundamental costs of catalysts, membranes, an bipolar plates; improving the carbon monoxide tolerance of the anode catalyst while reducing the carbon monoxide content in the reformed fuel, and improving the transient performance of the fuel processor/fuel cell system. As mentioned before, the problem remains in water management, both in the electrode and in the PEM itself. The most recent results from improved membranes, alternative proton conductors in the electrodes, and cells designed to sustain the hydration of the components suggest

that this goal can be achieved. In parallel with this effort, work needs to continue in the areas of membrane transport and carbon monoxide tolerance. Advances in these areas then can be incorporated into the fuel cell design to provide higher power density and good performance on reformed methanol containing small amounts of carbon monoxide.

Senator EVANS. Please go ahead, Mr. Harrington.

STATEMENT OF RICHARD E. HARRINGTON, DEPUTY ASSISTANT SECRETARY FOR COAL UTILIZATION, ADVANCED CONVERSION, AND GASIFICATION, OFFICE OF FOSSIL ENERGY, DEPARTMENT OF ENERGY

Mr. HARRINGTON. Mr. Chairman, I represent the Office of Fossil Energy within the Department. The Office of Fossil Energy currently oversees research on phosphoric acid, molten carbonate, and solid oxide fuel cells. These systems are predominantly suited for electric utility generation and for large industrial and commercial application.

As Dr. San Martin has indicated, these fuel cells are powered by an electrochemical combination of hydrogen and oxygen, with virtually any hydrocarbon fuel being a potential primary fuel for the production of hydrogen for use in the operation of fuel cells. For economic reasons, natural gas and coal represent the principal fuels, however, for the fuel cell systems that I have mentioned, alternately, alcohols and petroleum distillates can be used as sources of hydrogen, provided they can be reformed and provided the resulting hydrogen is clean to the point that the contaminants do not impair the function of the fuel cell.

The phosphoric acid fuel cell technology has been well proven but remains to be adopted commercially. The obstacles confronting phosphoric acid fuel cells are primarily economic in nature. The capital cost of a fuel cell is currently several times greater than alternatives such as gas turbines or even the conventional pulverized, coal-fired steam generation systems. While mass production may make phosphoric acid fuel cells more competitive, industry must be prepared to address the production and the marketing issues before the technology will see widespread commercial application.

In recent years, the Department's Office of Fossil Energy Research Program has begun to shift from the phosphoric acid technology that is nearing commercial application to more efficient but less developed technologies such as molten carbonate, solid oxide and solid polymer electrolytes. This is consistent with the administration's policy on targeting taxpayer dollars toward those research efforts that remain beyond the scope of private research and development.

I have provided in the attachments to our testimony submitted for the record detailed descriptions of the ongoing fuel cell efforts within the Office of Fossil Energy. These sections of my statement provide definitive explanations of the cost/benefits of the fuel cell program and their potential for application and their commercialization potential.

Suffice it to say in this hearing that fuel cell technology may be a promising energy supplier with attractive energy conversion efficiencies and environmental potential, provided the economic barriers that now exist can be overcome.

Thank you, Mr. Chairman.

Senator EVANS. Thank you.

Let me start with just some general questions on the whole, you know, on the whole area of priority determination within the Department of Energy.

Perhaps you will have to refer some of these questions to even the Secretary and get, to discern for us, if it is possible, what the priorities of the Department are and how they are established.

I am concerned, I think many of my colleagues are, about some seemingly large disparities in where we spend our research money, how much goes to one technology versus another. I am curious as to how you determine what process you go through, and do you think you are adequately assessing the amount of money required for each of the alternative energy technologies that are now under research and development? Are some being overfunded, some being underfunded?

How sure are you that you are really giving the winners a chance to emerge and not strangling some of them almost at birth?

Dr. SAN MARTIN. Mr. Chairman, as you well realize, that is a difficult question, at best, and one that we struggle with continually. Each of the operating elements has its own opportunity to consultation not only with our national laboratories but the industrial base in the country to try and assess what the state-of-the-art is and what the promise is that looms for the many options that are available.

In the Department of Energy, we have fostered a position where we would like to continue the development of many of the promising technologies that exist today. Within each organizational unit they undertake their own more detailed analysis to look at priorities among themselves, and then the major units working across the breadth of the Department undertake their own priority representation with the majority of the organizations, of course, being advocates for the promise of the technologies that they represent.

In that regard, we have attempted to represent to the Congress the state-of-the-art stands and, what the national needs might be in the next period of time. From this a budget is developed that is reasonably balanced among all of the various technology options.

Senator EVANS. To a degree, and then, presumably I would guess Congress would say essentially the same thing, that they attempt to respond in the same way to get that nice combination, and assuming that that is the case, why then when it comes to rescissions or, in this case, deferrals which you have proposed for fiscal year 1986, it seems to me that if you had got this nice balance all the way through, that any deferrals ought to be essentially across the board, equal percentages, but they are not. There are wide differences in the priorities of deferrals which do not have much correspondence to the initial budget, or the budget as it was devised through Congress and the administration.

How come?

Dr. SAN MARTIN. Mr. Chairman, the general policy on which we have been operating, with regard to deferrals in fiscal year 1986 is the policy decision was made across the Federal Government to propose deferrals for all of the specific add-ons that were made during the appropriations process. Obviously this was motivated by the strong drive to get total expenditures under better control and

try to work harder toward some of the deficit issues that we all collectively face.

Senator EVANS. In other words, what you are saying, you want to totally ignore the actions of Congress on the budget of fiscal year 1986 and pretend like it never happened. Is that not an accurate presumption?

Dr. SAN MARTIN. Mr. Chairman, the position was rendered as a policy across the board.

Senator EVANS. Is that answer yes or no?

It sounds to me like it is a yes. I am sure it came from higher in the administration. I think you ought to take back to whoever it is higher in the administration that this Senator, at least, and I suspect many of my colleagues, feel that that is precisely what has happened in terms of budget deferrals, a new way to essentially go your own way and ignore the whole range of congressional decisions which have been made in the budgetary process by just refusing to respond to them.

Mr. HARRINGTON. Mr. Chairman, if I might add to that, as has been pointed out, we do have the task, as do you, of trying to carry out a delicate balancing act, and in fact, we try to take into consideration such factors as the relative maturity of certain of these technologies. For example, you will recognize that the phosphoric acid fuel cell technology is one of the technologies that represents a fairly large percentage of the proposed deferral. We made this judgment recognizing the maturity of this technology and that it is in fact to the point of being offered to the private sector as a commercially available technology.

Consistent with earlier comments, we have attempted to focus our research and development attention on those technologies which have promising potential but are much less mature in the overall research and development pipeline.

So this is another consideration in trying to make these priority selections.

Senator EVANS. That does not sound like the same answer I heard from your colleague, which was that you cut back where the Congress had added on.

Mr. HARRINGTON. Sir, they happen to be concurrent in this case. [Laughter.]

Mr. HARRINGTON. The Congress in fact, as you know, did add on a substantial amount for the phosphoric acid fuel cell program, which represents a very mature technology.

Senator EVANS. Does that not really get back to the original question, that you made the decision a year ago, and Congress modified it based on the hearings and information and decisions that were made through Congress, and that budget was carried through and ultimately signed by your President, our President. That was the budget that went into effect, and now you are going back to that same square and said that, you know, we were right a year ago, and we do not care to pay any attention at all to the decisions that were made by Congress and the budget that was signed by the President. We are just going back and spend on that original concept.

Is that not an accurate statement?

Dr. SAN MARTIN. Mr. Chairman, there are many ways to represent the context for how the communications take place between our two bodies, but it is accurate that many of the items that have been proposed for deferrals, not all of them, but many of them, are items that have considerable interest within the Congress. We would hope that in the deliberation of all of the programs that there is still sufficient ongoing high priority activities that we are making meaningful progress in developing these technologies.

Senator EVANS. Well, I will not proceed immediately on that. I will turn to my colleague, Senator Ford, who has not had an opportunity yet to——

Senator FORD. Mr. Chairman, could we turn the microphones up out there? I am not quite—I want to be sure I get everything clear. It is——

Senator EVANS. Even if you hear it, I am not sure it will be clear. [Laughter.]

Senator FORD. Well, the possibilities of it being clear, Mr. Chairman, would be much better.

Senator EVANS. I think it would help if—you have to talk quite close to those microphones, and I do not know whether they can turn the sound up, but if you will keep right close to the microphones, perhaps you can hear.

Let me turn to Senator Ford, who has not had an opportunity to make any initial statements.

Why do you not continue with whatever questions you may have, Senator, at this point.

Senator FORD. Well, we usually go by attendance——

Senator EVANS. Well, I just want to offer you any initial comments.

Senator FORD. I have no opening statement, Mr. Chairman, but I sure have some questions.

Senator EVANS. All right. Well, then, let's proceed to Senator Bingaman.

Senator BINGAMAN. I almost want to defer and hear those questions. [Laughter.]

Let me see if I understand the administration policy to be whatever we add on to the budget, or the one that you sent us last year, you defer and do not spend. Since I assume we can expect that same policy in 1987, we are really wasting our time. So that if we add money in, as Senator Matsunaga would like, to this fuel cell area for the 1987 budget, I guess we can expect that the money will be deferred and not spent in 1987. Is that accurate?

Dr. SAN MARTIN. Mr. Chairman, it is my understanding of the process that even though, on the administration side, an across-the-board policy decision was made to defer these add-ons, that in fact those deferrals are something that have been proposed to the Congress.

Senator BINGAMAN. So we can expect you to offer up deferrals on anything we add on this year just like you are proposing to defer any spending that we added on from last year's budget. Is that right?

Dr. SAN MARTIN. Mr. Chairman, I would be hard pressed to try and predict what actions may result in the fiscal year 1987 budget, and therefore, what the needs of the country might be in future

years. As we all realize, there is great concern not only in the Administration but in the Congress on total Federal Government expenditures, trying to do whatever we all can collectively in working toward resolution of the major deficit problems that we face.

Senator EVANS. Senator, if you would just defer for a moment, I just want to get one thing clear. You say you have offered up the deferrals. That is not quite accurate, is it? Do you understand correctly that there is considerable difference between rescission and a deferral, that a rescission must be placed before Congress and be approved; a deferral takes effect unless Congress, with both Houses acting, denies that opportunity.

Is that your understanding?

Dr. SAN MARTIN. That is my understanding of the process, Mr. Chairman.

Senator EVANS. Why did you not ask for a rescission and ask for Congress action instead of deferral, and requiring Congress to deny?

Dr. SAN MARTIN. I don't know the answer to that, Mr. Chairman.

Senator EVANS. Thank you.

Senator Bingaman.

Senator BINGAMAN. Let me ask about a specific issue. Here on the last page or next to the last page of your testimony, you talk about this proton exchange membrane technology, and indicate the "research of the past several years has increased our confidence that PEM based fuel cells are the most promising technology for widespread use in the transportation sector."

Why are we proposing to cut funding there in that research?

Dr. SAN MARTIN. Mr. Chairman, I would also like, as you have done, to speak positively about the potential for proton exchange membrane types of fuel cells. At the same time that we are faced with this opportunity and many others, we have proposed to undertake a reduction of funding in 1987, but we still believe that the most important core of the work that can lead to future advancements in the technology, is preserved in the budget that has been presented.

Senator BINGAMAN. I am not sure I understand that answer. Overall, the Energy Department is getting an increase, or asking for an increase in research and development funds, right?

Dr. SAN MARTIN. There is a slight increase that has been requested in all of the basic energy research activities. The request that we have made in fiscal year 1987 in the applied technology areas that include conservation and renewables, fossil energy, etc., does represent a decrease from the levels that were requested in 1986.

Senator BINGAMAN. Well, I have got the budget that was presented to us by Secretary Herrington. It says that there is $5,134,000,000 in 1986, $5,289,000,000 in 1987 for research and development.

Dr. SAN MARTIN. Yes, Mr. Chairman, once you add in to what I have already cited all of the basic research and development that supports all materials work, for example, that is generic. Even though some of it may go on in the defense programs, the sum of all that accurately represents the numbers you just quoted.

Senator BINGAMAN. But this is one piece of basic research, and you would agree, would you not, that the money we are putting into proton exchange membrane technology development is basic research.

Dr. SAN MARTIN. Part of the work going on in that area, yes, sir, is very basic research.

Senator BINGAMAN. This is one piece of basic research that you have slated for a major cut at the same time that these other areas of basic research are going up, is that not right?

Dr. SAN MARTIN. Mr. Chairman, that is what the numbers say.

Senator BINGAMAN. And this is, in your opinion, the most promising technology for widespread use in the transportation sector that you know about, and you slated it for a major cut.

Dr. SAN MARTIN. Mr. Chairman, I did not start from that particular premise. I believe that among the fuel cell options that for transportation applications, this is the most promising one. There are other types of options available for transportation applications, and they are competing with this particular technology. Which one of them ends up being the most promising in the longer term will depend on how well we, working with the various scientists and engineers in the Nation, can develop these particular technologies. We have to realize the fruits of our endeavor before you can state with great confidence what the best technology option is going to be.

Senator BINGAMAN. It sounds a little bit like we have got a catch-22 here. Those technologies that are mature we can cut because they are mature and ready for commercial application. Those that are not not mature we can cut because we do not know whether or not they are going to develop or not.

Is that a reasonable description of what you are saying?

Dr. SAN MARTIN. With regards to the technologies that are maturing, Mr. Bingaman, I think it is very appropriate that we rely more and more on the private sector to use their own innovation capabilities to continue that particular process.

The applied research is traditionally carried in the various organizations through numerous budget categories. We also have been looking at budget cuts in fiscal year 1987. This area, as in many of the other promising areas, incurring a budget reduction in 1987 and involve difficult decisions on our part with respect to technical priorities.

Senator BINGAMAN. But you would agree, would you not, that since this is basic research, if we do not fund it, it will not be done in this country.

Is that reasonable? It may be done, but it will not be done in this country.

Dr. SAN MARTIN. Senator Bingaman, I think this concept is sufficiently promising that it will be done in this country.

Senator Bingaman: Who is going to do it?

Dr. SAN MARTIN. Between the efforts that I believe will continue in the Department of Energy and interest that exists in this technology in other places that are conducting electrochemical research and in much of the related scientific phenomena, I think that you will see methodical progress. I think that the primary argument is

whether the country's best served by developing this technology at the fastest pace possible or in a more methodical pace.

Senator BINGAMAN. And how do you answer that question?

Dr. SAN MARTIN. Within available resources, I think we should work toward the fruits of this technology as fast as we can. I think we should do everything that we can to leverage whatever the taxpayers 'investment is in developing these technologies. I think we should use all of our resources to encourage the private sector to invest more in these technologies and to share with them our own view of why they are promising.

Senator BINGAMAN. Well, let me just ask one final question for this first round. I understand both the Japanese and the West Germans have made very significant investments in research in this area, and they are moving ahead rapidly, and they are not cutting their budgets significantly this year and shifting them into defense related investments.

Is that consistent with your information?

Dr. SAN MARTIN. I am well aware, Senator Bingaman, of the work that they have ongoing in those other countries, but I believe that the record would indicate that the total amount of effort that has gone on in this country is quite substantial and maybe even overwhelming as far as the investment in the new technology that has been developed in other countries.

I also, some of the work that has gone on in this country on the commercial side is continuing right now by a joint venture of an American company with a Japanese company.

Senator BINGAMAN. Let me just ask if you think that 5 or 10 years from now we are going to be buying fuel cells from the Germans and the Japanese because we have decided against helping develop our own commercial capability here in this country. That is what this proposed budget does, correct?

Dr. SAN MARTIN. Senator Bingaman, for the application for transportation, I think that we are certainly holding our own in this country in developing this particular option.

With regards to other than transportation applications, would my colleague like to respond?

Mr. HARRINGTON. Yes. I think that the technologies that you are referring to, particularly in Japan, do in fact represent an export of some of the technologies which have been developed here. In most of the cases, however, these joint ventures take the form of just that, joint ventures between companies in Japan and the United States. In the case of at least one, which is the largest of these, the ICF group, the initial fabrication is planned or scheduled to be accomplished here in this country.

It would be difficult for me to say whether or not we would be buying components from Japan or Germany. I think that is probably more a matter of economics than it is one of technology development.

Senator BINGAMAN. I will defer to other, Mr. Chairman.

Thank you.

Senator EVANS. Senator Hecht.

Senator FORD. May I ask a question?

Are they operating under United States patents or Japanese patents on the joint venture?

Mr. HARRINGTON. Those are U.S. patents, Senator.

Senator FORD. So we are exporting our patents?

Mr. HARRINGTON. Yes, sir.

Senator FORD. That is all. That was all you had to do was say yes, sir.

Senator HECHT. Thank you, Mr. Chairman.

Just so I get the position absolutely clear, is the aministration supporting these two measures or not supporting them?

Dr. SAN MARTIN. Senator, are you referring to the legislation?

Senator HECHT. Yes, S. 1686 and S. 1687.

Dr. SAN MARTIN. We are not supporting the legislation, Senator.

Senator HECHT. You are not.

That is all I had, Mr. Chairman.

Senator EVANS. Senator Ford.

Senator FORD. I think it is obvious, Mr. Chairman, to all of us what is happening. We have had Secretaries in before this committee who have said we do not care what you appropriate, we are not going to spend it, and I think these gentlemen ought to be as forthcoming as their superiors.

Let me just ask you a question, then, Mr. Undersecretary, Mr. San Martin, if that is correct. Has DOE proposed deferring $22 million of the $35 million Congress appropriated for fuel cells this past year?

The answer is yes, is it not?

Mr. HARRINGTON. Yes, Senator, that is correct.

Senator FORD. All right.

Because this is a deferral and not a rescission, you do intend to spend this deferral money in 1987, do you not?

Mr. HARRINGTON. My understanding of the connotation of a deferral is that it is, in fact, being deferred for future use.

Senator FORD. No, that is not what I asked you. I know Webster's definition of a deferral. I am going to get your dimples out here in a minute.

You do intend to spend this $22 million next year, do you not?

Mr. HARRINGTON. I would assume that we do.

Senator FORD. You know, do you spell assume?

Mr. HARRINGTON. Yes, sir.

Senator FORD. You know, this is what happens to us here, and this is why we get into the confrontations we do, because you do not level with us, and you try to play dancing around the mulberry tree. Maybe we just ought to stop it and crush it and drink it, the mulberries, you know.

What specifically will you do with the $22 million in the fiscal year 1987, and when will you spend it if you assume you are going to spend it?

Mr. HARRINGTON. Senator, I understand that it is being proposed as an offset to the 1987 budget request. I would like to make the point that I am not trying to dance with you. I am trying to be cautious in responding to you strictly on the basis of the information that I know about.

Senator FORD. Well, let's get back to the $22 million.

You only requested $5 million. How could $22 million be an offset? You would have $17 million surplus then, would you not?

Mr. HARRINGTON. I would assume that it would be used to offset funding in other program areas.

Senator FORD. Oh, so you only want $5 million. You are going to defer $22 million, only request $5 million, and use the $17 million in other areas.

Mr. HARRINGTON. The program, Senator, is as we have been discussing, an attempt to try to balance and apply the resources in the areas where we feel that they have the most benefit to R&D.

Senator FORD. So what you are doing is deferring the $17 million in fuel cells, and you are saying for the record that you are going to use it in other areas in 1987, that you really do not intend to defer it to be used in fuel cells in 1987, you intend to use it in other areas, is that correct?

Mr. HARRINGTON. I am hesitating, Senator, because I am not sufficiently familiar with the budgeting process to know whether, in fact, it is restricted to being applied in the fiscal year 1987 budget request for fuel cells.

Senator FORD. Well, if you do not know anything about the budget, why are you here with Mr. San Martin?

Mr. HARRINGTON. Now, I think I do know something about the budgeting process.

Senator FORD. Well, you just said you did not know enough about the budget to——

Mr. HARRINGTON. I was trying to respond to your specific question, Senator.

Senator FORD. Well, I am trying to get a specific answer, and that seems to be very difficult to do.

Mr. HARRINGTON. I am doing the best I can.

Senator FORD. Well, it just indicates—well, let's look at another point, then.

Of the budget request, am I correct that 64 percent of the budget for DOE will be for the militarization of DOE. This is 84 percent of DOE's contribution to the deficit, because under the civilian use, there is some return on your money. Under the military use, it is all spent, so therefore, 84 percent of this particular area is a contribution to the deficit, is that correct, the overall DOE budget?

Dr. SAN MARTIN. Mr. Chairman, I have not brought with me an analysis of the budget to dispute or confirm the numbers. I expect that you have added up columns that are there and that the numbers are accurate.

Senator FORD. Well, Mr. Chairman, we are just seeing this every day. You talk about transportation, you are zilching most of transportation, even the collection and analysis of transportation energy data, that is zero.

On the information as it relates to mandatory printing of a distribution of the mileage energy use, that is being thrown out. You are going to leave it up to the private sector to do.

Is that called privatizing? Is that the new word we have got now, you know, "privatizing," let industry do it, sell off Bonneville, sell off TVA, sell off land between the lakes, sell off Elk Hills, just begin to do all these sort of things? Is that part of the privatizing that you are starting in DOE, that you are going to get out of all the consumer energy business and just stay in the military business?

Dr. SAN MARTIN. Mr. Chairman, Senator Ford, my knowledge of the various privatization and defederalization initiatives is what I have read. This is in areas other than the ones for which I am responsible. There is a very strong push, as I have become aware, to try and get the private sector and local decisionmaking much more involved in all of the activities.

Senator FORD. Well, let's just say that research and development, civilian programs generate some income, and the military does not, is that correct?

Dr. SAN MARTIN. Senator Ford, it is very difficult for me to dispute the value of stability and national security, and, therefore, investment in defense activities. The civilian research and development is an important part of the ongoing work and one that is addressed not only by the Department of Energy but many other organizations in the Federal Government and throughout the country.

Senator FORD. Well, let me ask you this. Mr. Chairman, I apologize for taking so long, but I think we are making points here today, and I think we are all on the same wavelength, at least on this side of the table.

In your deferrals, there is a very disturbing undercurrent that bothers a good many of us as it relates to research and development, that for all practical purposes you are going to phase out a program.

Does it not cost a great deal just to phase it out or to quit? Are you not looking at expenditures of moneys that would cost us as it relates to our ability to do research and development? Are we not just moving out completely in the civilian arena and saying that to Congress when you send up a list of deferrals that amount to almost $1¾ billion, and when you begin to look at all the areas, energy supply R&D, renewables, basic energy science, energy conservation, uranium enrichment, fossil energy, Naval Petroleum Reserve, power marketing, Strategic Petroleum Reserve, you just go down the list and look at what you are trying to do in your deferrals, you are just getting what you want by deferrals, and a deferral this year, and a deferral next year, and another deferral, that is a rescission, a rose by any other name.

Would you not agree with that?

What are you doing with programs as you defer, what happens to those programs? I mean, if you are going to defer $22 million in fuel cells, you are only asking for $5 million, $17 million is being used to put into other areas, what is happening to the cells? What happens to their research? What happens to their development? Where are you?

Dr. SAN MARTIN. Senator Ford, in the Office of Renewable Energy we have not proposed any deferral of work in the fuel cell area. We have proposed other deferrals that amount to about 11 percent of the total budget authority for fiscal year 1986. Our intent is to propose deferrals in lieu of new appropriation authority that is required for fiscal year 1987.

Senator FORD. Mr. Chairman, I will not carry this any further I just hope that some of the witnesses that follow these two will tell us what has happened, what will happen, what they expect to happen under the circumstances.

Senator EVANS. Thank you, Senator Ford, and if Senator Matsunaga would—well, why do you not go ahead, and then I have got to pursue the same line of questioning because I am more confused now than when we asked the first question.

Senator Matsunaga.

Senator MATSUNAGA. Thank you, Mr. Chairman.

Dr. San Martin, I have appreciated very much the effort you have made in promoting alternative sources of energy research in Hawaii, but then I am somewhat dismayed at your testimony this morning. I can understand that you are under extreme pressure from above and perhaps this may be a continuation of your—well, I would not say your, I would say the administration's effort to dismantle the Department of Energy, but assuming that you were testifying as an expert for the private sector, would you not be testifying in favor of the two bills rather than saying it is not required, as you say on page 6 of your testimony?

Dr. SAN MARTIN. Senator Matsunaga, I believe that as an individual and a representative of the Department of Energy, I would testify positively to the spirit of what is intended in the proposed legislation. I believe that the continued and future development of fuel cell technology is a positive thing to do. The continued development of alternative energy sources and renewable energy sources is a positive thing to do, and we have had many conversations on that particular topic. But I would also argue that if you——

Senator MATSUNAGA. If you would stop before the "but," I would be happy. I feel my confidence in you has been renewed.

Dr. SAN MARTIN. Without the "but," Senator Matsunaga, I think that we do have a number of authorities which do allow us to proceed along a path to continue development of these various technologies, and therefore we believe that we can continue that development process.

Senator MATSUNAGA. Well, I have had the privilege of reading some of the testimony to be presented later, and we have a witness, the vice president of R&D of Westinghouse, who will offer testimony later, and he says that if we maintain our lead through national support of fuel cell R&D, which he judges to be about 5 years, and "we can maintain the Japanese and all other countries as well as customers for our equipment." And the recent report of the Office of Technology Assessment on new—this is not the quote, but the recent report of the Office of Technology Assessment on new electric power technology states that while we have had an edge in photovoltaic technologies: "European and Japanese vendors, assisted by their respective governments, have been more successful than U.S. vendors in developing these markets."

Do you not believe that the same will be said in the very near future of fuel cell technology if the Federal Government does not pursue the course suggested by the two bills?

Dr. SAN MARTIN. Senator Matsunaga, I think that as long as progress is being made, the U.S. industry can hold their own in international competition. The other examples that you gave, which are real world examples, indicate that the market share has been changing among various countries who have been aggressively pursuing different types of technology. For example, in photovol-

taics, specifically, with which I am quite familiar, the market share has changed quite a bit during the past 12 months.

I am very pleased to represent that photovoltaics conversion of sunlight to power, not to consumer products, that the United States is doing very well and holding its own, and making advancements in the technology at a pretty fast clip.

Senator MATSUNAGA. But only by virtue of the tax credit which the Federal Government has provided upon the insistence of the Congress, has it not, and the administration is once again proposing, as it has proposed year after year, to eliminate such incentives, to eliminate the tax incentives, and how in the world, without providing incentives to the private sector, can we expect the private sector to go ahead on its own initiative?

Well, that is a statement, not a question. So I thank the chairman for allowing me as a nonmember of the committee to participate in the questioning.

Senator EVANS. We are delighted to have you do so.

Before we–I am afraid we are flogging a dead horse here, but I will try once more to revive it.

I am not sure that—I am just curious now whether you are accurate in stating, using as an example, the $22 million deferral for fuel cells, a $5 million request for next year, that somehow you could use the $17 million net for some other program.

It is my understanding that in the President's budget presentation, he was obliged under the new Gramm-Rudman procedures to submit a budget that would end with a deficit of $144 billion.

In order to get there, he not only submitted a fiscal year 1987 budget, but in addition to that, submitted some deferrals and some rescissions for fiscal year 1986, and it required those deferrals and those rescissions and the budget for fiscal year 1987 to get that deficit down to $144 billion.

Is that your understanding?

Mr. HARRINGTON. I believe that's correct, sir.

Senator EVANS. OK. Well, I believe that is a correct understanding. We should have Senator Domenici still here, I guess, but we will have to ask those questions then in writing because I think it is critically important to find out what the understanding—what your understanding is which I think is at variance with the facts as they were submitted in the President's budget.

It is bad enough to have the deferrals as a way of ignoring congressional intent, which has clearly been done here. It is even worse to take those deferrals and to apply them where you wish in the new budget without any kind of congressonial approval and just willy-nilly spread them wherever you want. Presumably you could take this $1,600 million worth of deferrals, and unless Congress denies you those opportunities, you could take the whole $1,600 million and throw it into militarily related energy activities if you chose to under what I heard you say.

I do not think that is accurate, but nonetheless, it would represent a serious distortion of any kind of congressional budget, and I do not know what we are doing here if we continuously provide budget direction and pass an appropriation bill or a series of them, and the President signs them, and his—and I know a little bit as the Chief Executive about the oath we take, which is to faithfully

execute the laws of the United States, and to distort a budget he has signed by the amount suggested here I think calls into serious question that kind of activity.

And I will not even ask the question because it is obvious that, you know, the budget share of this is somewhere else in the Department, and we will ask those in writing.

I should just say in conclusion that I suspect the only way out may be to include in each of our appropriation acts that the Secretary and top officials of each department will draw their salaries down in direct proportion to the expenditures they make from appropriations that are given to them, and maybe we will get the appropriations without deferrals.

All right, well, thank you very much for your--you have been grilled pretty thoroughly. We will have some written questions, particularly with relationship to deferrals and their activities.

With that, let us turn to Dr. Fritz Kalhammer, the vice president and director, energy management utilization division of the Electric Power Research Institute, and David Webb, senior vice president, policy and regulatory affairs of the Gas Research Institute.

We would like to have you summarize your written testimony, and I would announce at this time that all of the written testimony of all witnesses will be included in full in the record.

If we can do that, we can then get to some of the questions that I am sure that Senator Matsunaga and Senator Ford and I would like to ask.

Please proceed, Dr. Kalhammer. It is a pleasure to see you again.

STATEMENT OF DR. FRITZ R. KALHAMMER, VICE PRESIDENT, ENERGY MANAGEMENT AND UTILIZATION DIVISION, ELECTRIC POWER RESEARCH INSTITUTE

Dr. KALHAMMER. Mr. Chairman, members of the subcommittee, I sm Fritz Kalhammer, vice president for the energy management and utilization division of the Electric Power Research Institute.

I would like to thank you for the opportunity to express some views here on the key issues that surround the development and commercialization of the fuel cell.

I have submitted a written statement which I will briefly summarize here, hitting only the key points. I would like to focus here specifically on the issues regarding the development and commercialization of the phosphoric acid fuel cell for electric utility service.

The comments that I am presenting here are from the viewpoint of EPRI, an organization that has made an investment of more than $50 million in the development of the phosphoric acid fuel cell technology, doing so for an electric power industry that in itself, and in addition to the EPRI investment, has provided another $50 million for development support for phosphoric acid fuel cell technologies.

I am stressing this point because I believe that this investment does attest to the importance that the electric utilities accord the phosphoric acid fuel cell as a new generating option with a series of characteristics that have been summarized so well by three dis-

tinguished Senators. I do not have to repeat that therefore, but there is obviously a very high level of interest.

The second point that I would like to make is that these large investments by the electric utilities, by commercial vendors in comparable amounts, and certainly by the Department of Energy and its predecessors, has largely been successful. We have been able in this concerted, coordinated, national effort to bring the phosphoric acid fuel cell technology from the status of a concept in the laboratory in the early 1970's to the point where we are on the verge of commercializing the phosphoric acid fuel cell technology for electric utility service, where it could become the first new, very attractive because it is well matched to utility needs, power technology in a quarter of a century.

However, and as I noted in my statement, we are facing a dilemma right now. The early units that are now being offered as evaluation units by an industrial venture clearly are going to be more expensive. They are also going to carry a higher technoeconomic risk than competing technologies. Clearly this is so because the technologies that utilities can buy today, conventional technologies, have had a long course of development and commercal practice. The fuel cell has not.

As a consequence of the risk due to the higher costs and also to a larger uncertainty regarding reliability, durability, and so on, there is uncertainty on the part of electric utilities, and that makes utilities reluctant to commit to a program of these early evaluation units.

Now, I noted in my statement also that there are a number of steps that can be taken to mitigate and perhaps overcome these risks and proceed to commercialization. I would stress that I think one of the most important measures and steps to be taken is clearly the continuation of research and development to improve the phosphoric acid technology. Not only will this technology R&D allow the technology to go down in costs, become more reliable and more durable, in fact, as we go down the technology learning curve, but it is also going to be perceived by the electric utilities who are facing the question of a commitment as an assurance that this technological learning is going to continue to occur, so that if they now commit to early units, they can do so with some confidence that a more mature technology will eventually be available to them commercially.

So, continued R&D, I think, is key. The Electric Power Research Institute is certainly committing in its programs to allocate as much money as possible to that R&D, but there is absolutely no question in our minds that continued participation by the Department of Energy in this kind of work is crucial. The private sector is spending its resources on accepting the risks of the higher costs of these units, is accepting the risks of making investments that allows the technology to be produced, is making an investment, at least incrementally, through EPRI to address open, technological questions and cost reduction, but there is a large amount of work still to be done, and that will be very cost-effective work, and I think that is a proper task for the Department of Energy.

I would make two more points on things that I think need to be done to expedite and accelerate commercialization, to take advan-

tage of past investments. Clearly, there is a need for electric utilities to better understand the value of the fuel cell for their operations. Fuel cell is a new kind of device. It does more things, it does different things, from conventional power generation. There is a need to quantify that so that utilities will know how much they can afford to pay.

EPRI is working with a number of utilities in the fuel cell users group to put dollars on these special benefits, and I am encouraged that our work shows that such benefits are real and eventually they will be available to offset some of the extra costs. That I think is an appropriate role for private industry and EPRI supporting its own industry.

There is one other somewhat more knotty issue, which has to do with general reduction of risks. Clearly, the key step that needs to happen now is for these evaluation units to be committed to by utilities that are willing to be early users of the technology. Clearly, we need R&D to reassure that technology learning is occurring, but the risks that are being perceived today by utilities and by their vendors because of the uncertainties that surround them in terms of load growth, in terms of market viability, in terms of regulatory allowance for new technology—I think these risks need to be addressed somehow. It may be well beyond the scope of this hearing, but I would submit for consideration by the Senate and by the Congress measures that might assist the introduction of new technologies while they cost more and carry higher risks, whether these might be special regulatory policies, or maybe incentives, whether it might be, let's say, a fuel-price guarantee, or an energy-price guarantee, I should have said, like the one that SFC provided for cool water which made a crucial difference for that program.

I think these are the kinds of measures that somehow need to be contemplated and hopefully implemented to assist this process.

Let me just very briefly summarize, and I am almost through. We, certainly at EPRI, support the spirit of the two Senate bills that are the focus of this hearing because they do tend to expand the applicability of fuel cells. We certainly believe that fuel cells do have a realistic chance to make it commercially in the electric power generation application.

We do believe that continued R&D, including a vigorous program by the Federal Government is going to be crucial to get us passed some of the hurdles, and we do believe that there needs to be consideration given to other measures that help expedite the introduction of new technologies that carry extra costs and risks in their early introduction phase.

I think the fuel cell is a model that can serve also for many cases of other advanced technologies, and we believe it is very important that the example of the fuel cell, some of the salient issues are being discussed and that the Federal Government, including DOE, play a vigorous role in their support.

Thank you, very much.

[The prepared statement of Dr. Kalhammer follows:]

STATEMENT OF FRITZ R. KALHAMMER
VICE PRESIDENT, ENERGY MANAGEMENT AND UTILIZATION DIVISION
ELECTRIC POWER RESEARCH INSTITUTE
to the
SUBCOMMITTEE ON ENERGY AND NATURAL RESOURCES
U.S. SENATE
February 24, 1986

Mr. Chairman, Members of the Subcommittee:

I am Fritz R. Kalhammer, Vice President and Director of the Energy Management and Utilization Division of the Electric Power Research Institute (EPRI). I appreciate this opportunity to participate in this hearing and provide you with our views on fuel cells and the key issues surrounding their development and commercial introduction.

The Electric Power Research Institute was established by the Electric Utility Industry in 1972 to conduct a broad research and development program for the entire electric utility industry and its rate payers. EPRI's R&D mission is to develop new and improved technologies for electric power production, delivery and use; and to help accelerate the availability of these technologies to ensure an adequate supply of economic, reliable and environmentally acceptable electricity. EPRI's 1986 R&D program is funded at approximately $250 million by voluntary contributions from public and private utilities from all parts of the U.S.

Fuel Cell R&D was among the earliest activities established within the EPRI program, with EPRI taking over responsibility for the programs initiated by a group of interested utilities. This interest, then and today, derives from the fuel cell's unique characteristics:

1. High efficiency, with early technology expected to equal the efficiency of the best currently available electric power plants, and advanced fuel cell technology promising to reduce fuel consumption by as much as one third from current levels.

2. Negligible environmental impact, with emissions well below permissible levels for all air pollutants.

3. Modularity, offering the benefits of high efficiency and negligible emissions in small, factory assembled units that can be ordered with short lead time, added incrementally according to demand, and installed on sites not feasible for conventional power generators.

4. Economic recovery and utilization of power plant waste heat, for total energy efficiencies of 80% or more.

5. Operating advantages such as rapid electric response, high efficiency at part load and minimal water consumption, all of which will improve the efficiency and adaptability of future electric power systems.

These characteristics promise to make the fuel cell a power generating option that will offer utilities a previously unattainable combination of high efficiency, environmental compatibility, and planning as well as operating flexibility.

Through more than a decade of intensive R&D, funded by the private sector and the Federal Government at a total level exceeding $300 million, the phosphoric acid fuel cell--the leading fuel cell technology--has been developed to the point where many of the expected advantages have been proven out. In particular, the 4.8 MW demonstration projects in New York and Tokyo have validated the siting, assembly, environmental compatibility, performance and operability characteristics of fuel cell power plants. As expected, these projects also have identified several aspects of the technology which require improvement, and they have helped guide R&D toward the most promising technical solutions.

The translation of all these developments into a fully commercial, competitive power plant product and the beginning use of this advantageous power generation option by utilities now hinge on the resolution of a dilemma. The components of this dilemma--which is typical for the commercialization of potentially beneficial electric energy supply technologies--are:

- Early production units will cost more and carry a higher risk than long-established, competing technologies;
- utilities are reluctant or unable to buy the higher cost early units, for several reasons:
  - the risk they perceive for fuel cells as a new technology that has not yet fully demonstrated its roles, reliability and durability in electric utility service,
  - the difficulty they have in quantifying the value of the special benefits provided by fuel cells and, thus, their inability to justify higher capital costs,
  - their perception that significant uncertainties exist with respect to future load growth and needs for capacity, probable cost and availability of fuels, and also with respect to future costs of the new technology and its availability from vendors;
- without clear commitments from utilities, prospective vendors will not invest in the automated production facilities required to reduce the cost of fuel cells as a largely factory-built technology to the levels that will assure broad markets.

In the view of EPRI, a number of steps can and should be taken in an attempt to resolve this dilemma:

- Cost and risk reduction - while major progress has been achieved in both regards, continued R&D is almost certain to result in improved or entirely new technical approaches that will reduce phosphoric acid fuel cell power plant cost and, through improvements in reliability, durability and maintainability, also reduce utility financial risk. Such R&D needs to address both near-term problems and longer-term opportunities, and it needs to be conducted on the component, subsystem and power plant/system levels. Continued Federal and private sector support of this R&D will be critical for the reduction of costs and risks to levels that will encourage utility commitments.

- Value perception - with the assistance of the Fuel Cell Users Group and EPRI, utilities have established that several of the unique characteristics of fuel cells could have economic benefits. The value of these benefits needs to be quantified to the point where they become factors in decision making by utilities (and, where appropriate, their commissions) regarding commitments to early and mature fuel cell power plants. EPRI and a number of individual utilities are already addressing this quantification task which poses novel and difficult analytical problems. We expect this work to confirm the likelihood of significant benefits that, if confirmed by actual deployment and operations of fuel cell power plants, could offset some or all of the extra costs.

- Dealing with uncertainty - the major uncertainties referred to earlier in this testimony, are not generally subject to control by utilities or manufacturers. This fact poses the question as to how one can assure the timely availability of technologies such as fuel cells that provide utilities with the capability of cost-effective short-term, low-risk responses to uncertainty in future demand--when this very uncertainty tends to prevent the actions needed now to insure future availability. Among others, utility planning under uncertainty, the value of risk-reducing technical strategies, and the proper treatment of the costs of such strategies as prudent business expenses need to be addressed to help resolve this dilemma. Similarly, how can uncertainties in fuel costs and availability be dealt with? Possible responses include appropriate regulatory treatment, Federal incentives (such as price guarantees); and R&D support for technical strategies that further expand the multi-fuel capability of fuel cells.

  Constructive responses to these questions would very likely expedite utility decisions to commit to fuel cells and, thus, would strengthen vendor resolve to continue their investment in development and commercialization of fuel cell technology.

As noted above, several of these steps are already being taken in current programs to develop and commercialize fuel cells. If these programs are to succeed, then ongoing coordinated national efforts need to be continued and appropriately expanded. Specifically:

- Support for R&D to reduce costs, improve durability and enhance performance of phosphoric acid fuel cells needs to be continued. These efforts need to address both the critical components of emerging prototypical technology as well as opportunities for future advances in cost, efficiency and fuel versatility. EPRI intends to continue funding of these activities at $1.0-2.0 million/year during the introductory phases of phosphoric acid power plants, but a higher funding level is required for adequate progress in critical areas. It is important and appropriate that Federal support of R&DS in these areas is continued.

- Manufacturers and utilities need to proceed with fabrication, deployment, operation and improvement of fuel cells through programs involving a limited number of commercial prototype power plants.

- Consideration needs to be given by the appropriate Federal and State agencies as to how the financial risks and institutional barriers faced by individual utilities and manufacturers in the commercial introduction of fuel cells might be reduced, to facilitate timely deployment and investment decisions.

- Federal and EPRI support need to be continued for longer-term, higher-risk fuel cell technologies (such as molten carbonate and solid oxide fuel cells) that promise large societal benefits if these developments are successful. EPRI intends to continue funding these activities at $2-2.5 million per year.

Mr. Chairman, some of the most important issues surrounding the development and commercial introduction of the fuel cell also apply to other advanced electric energy supply (generation and storage) technologies such as load levelling batteries, compressed air energy storage, and integrated gasifier/combined cycle power plants. In every case, the private sector and the Federal Government have made substantial and successful R&D investments because of the anticipated societal benefits of the technologies. Yet in every case, ultimate commercial success is threatened because the investment risks are perceived to be high and rewards uncertain, especially for utilities as a regulated industry. Federal support of R&D to reduce risk clearly is one crucial requirement for success. Beyond this R&D support, there is an urgent need to improve, through appropriate incentives and regulation, the reward/risk ratio for utilities and their vendors. We believe it is extremely important that this country demonstrate, at the example of the fuel cell, its ability to overcome not only the technical but also the institutional barriers that stand in the way of new and beneficial electric energy supply technologies.

Senator EVANS. Thank you.
Mr. Webb.

STATEMENT OF DAVID O. WEBB, SENIOR VICE PRESIDENT, POLICY AND REGULATORY AFFAIRS, GAS RESEARCH INSTITUTE

Mr. WEBB. Thank you, Mr. Chairman. I am David Webb, for the Gas Research Institute. I appreciate the opportunity to appear before you today to discuss GRI's experience with fuel cell research and development.

GRI has been involved with fuel cell research through joint programs with the Department of Energy since 1978. By the end of 1986, the gas industry, through GRI, will have committed over $65 million for development, testing, and demonstration of these prototype phosphoric acid onsite fuel cell powerplants. In addition, as an essential element of the GRI program, 31 gas utility company members have committed another $35 million over the past 7 years for field testing of these onsite fuel cell systems.

This combined gas industry funding of $100 million and the DOE program funding over the same 10 years of $54 million, has brought the development of the onsite fuel cell to a point where technology transfer and commercialization could be achieved in the 1989–1991 timeframe.

However, commercialization can only occur if we remain dedicated to the task of completing the final technology development, the verification phases of the prototype, commercial unit. It is critical to finish the research and provide the technology base necessary for the manufacturer to make a commercial offering to the gas industry. In my opinion, this is truly the best way that the consumer can start to receive some benefits from the tax dollars that are spent on R&D.

GRI is the gas industry's R&D agent. We are not a Government contractor. We do not accept Federal funds. However, we do cofund and coordinate our research with DOE. Therefore, the actions of Congress on the fiscal year 1986 deferral request, and the fiscal year 1987 DOE fuel cell budget have a direct impact on the gas industry's fuel cell research program.

Congress has recognized the importance of the fuel cell research in the past and has acted accordingly when considering the DOE budget request. As an example, appropriations for fuel cell research for fiscal year 1985 were about $40 million, and in fiscal year 1986, Congress added $26 million to the DOE budget request of $9.5 million to continue cost-shared fuel cell research.

Yet the DOE's 1987 budget, as we have already heard this morning, is for $5 million total for all fuel cell research and there also is a proposal to defer $22 million of the $26 million Congress added this past year. These deferrals, despite what has been said this morning, would cause abrupt terminations of major, ongoing, cost-shared, research projects with GRI, EPRI, and industry.

As a specific example, Congress appropriated $6 million in fiscal year 1986 to continue the cofunded, 50–50 cofunded project between GRI and DOE to develop technology for the onsite fuel cell system. DOE is now proposing to defer $3 million of this funding.

This program is even more critical in that GRI in 1982, along with the gas industry, agreed to assume the total cost of the field test part of the program, which the DOE said was too near term for their involvement. We did assume the total cost of that. We agreed to jointly fund the technology development on a 50–50 basis and entered into a 4-year contract in 1982 with this administration—not the previous administration.

Now they are proposing to defer that money. So what has happened is GRI and the gas industry picked up near-term research hoping to cofund the long-term research which now they are proposing to defer and essentially terminate that program when we are only 2 or 3 years ago from what we think is an honest change to commercialize the technology.

GRI would recommend the following congressional budget actions, take what actions are necessary to deny the request to defer the $22 million, and funding DOE in fiscal year 1987, a fuel cell budget, at a total about $25 million. This would be a 27-percent reduction from the fiscal year 1986 congressionally approved funding level, and I think would give enough resources, combined with those that GRI and EPRI and other manufacturers would provide to bring this program toward commercialization.

Regarding the gas industry's onsite fuel cell program, let me just give you a brief status. As of December 31, 1985, 46 out of 46 fuel cells, power cells, had been delivered to the host utility. We have accumulated over 240,000 hours of operating experience. The average availability of the fuel cells has been 63 percent; this includes accounting for not only scheduled but unscheduled maintenance time, and also getting the new units installed and operational at the site.

One of the units has run continuously for 90 days and 36 of the units have now run continuously for greater than 1,000 hours. So from a technical standpoint, all in all, it has been a very successful field test program.

Also, coordination is good. Many organizations have made significant commitments to phosphoric acid fuel cell development, including DOE, NASA, the Department of Defense, GRI and EPRI. All of these are members of the ad hoc National Fuel Cell Coordinating Group, which does coordinate fuel cell activities at a national level.

Commercialization potential is promising. Commercial offering to the gas industry of an on-site phosphoric acid fuel cell, probably in the 200-kilowatt range, is expected in mid-1986 from the manufacturer, with initial delivery of units planned for the 1989-91 time frame.

The remaining issue that has to be resolved is building a few of these 200-kilowatt size units, determine the true cost of those units, verifying the performance in the laboratory and in a few selected field sites so that the manufacturer and the gas industry utilities, with GRI out of the equation, then making an honest commercial deal with each other to try to bring these into commercial applications.

In summary, Mr. Chairman, a viable consistent, long-term fuel cell systems research program in DOE's Fossil Energy Program is required in 1987 if this Nation is to realize its goal of commercializing phosphoric acid fuel cell powerplants by 1990. A funding level

of approximately $25 million, which is a 27 percent from the 1986 appropriation levels, would allow critically jointly cofunded research to continue.

GRI is willing to cofund with DOE, on a 50-50 basis, the research necessary to do the final phase of technology development and verification of the onsite phosphoric acid fuel cell systems that we have been doing with DOE for the past 10 years.

That completes my statement, Mr. Chairman. I would be glad to respond to any questions.

[The prepared statement of Mr. Webb follows:]

STATEMENT OF DAVID O. WEBB, SENIOR VICE PRESIDENT
POLICY AND REGULATORY AFFAIRS, GAS RESEARCH INSTITUTE
BEFORE THE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
COMMITTEE ON ENERGY AND NATURAL RESOURCES
U.S. SENATE
FEBRUARY 24, 1986

I appreciate the opportunity to appear before you today to discuss the Gas Research Institute's (GRI) experience with onsite phosphoric acid fuel cell research and technology development. I will be making specific recommendations necessary for a continuing and viable joint federal government/industry long-term research and development program in fuel cell systems.

GRI has been involved in fuel cell research through joint programs with the Department of Energy (DOE) since 1978, and by the end of 1986, we will have committed over $65 million toward development, testing, and demonstration of a prototype onsite fuel cell power plant. In addition, as an essential element of the GRI program, 31 gas utility company members have committed $35 million during the past seven years for field testing the onsite fuel cell system.

This combined gas industry funding of $100 million and the DOE program funding of approximately $54 million has brought the development of the onsite phosphoric acid fuel cell to a point where technology transfer and commercialization could be achieved in the 1989-1991 time frame. However, commercialization can only occur if we remain dedicated to the task of completing the final technology development and verification phases of the prototype commercial unit. After nearly ten years and $150 million devoted to the joint DOE/gas industry research program, it is critical to finish the research and provide the technology base necessary for the manufacturer to make a commercial offering to the gas industry. This is truly the only way the consumers receive any benefits for their tax dollars.

GRI in an independent, not-for-profit scientific research organization that plans, manages, and develops financing for a cooperative research and development (R&D) program in end use, supply, transport, and storage of gaseous fuels for the mutual benefit of the gas industry and its customers. These mutual benefits can only be realized if the results of R&D are commercialized and used; consequently, GRI's policy is not to proceed with a project beyond the proof-of-concept stage without direct industry involvement. GRI implements its R&D program through contracts with research organizations, national laboratories, universities, energy companies, and manufacturers. Even though GRI is not a government contractor and does not accept federal funds, GRI has cofunded and coordinated its fuel cell research with DOE. Therefore, the actions of Congress on the FY 1986 and FY 1987 DOE fuel cell budget have a direct impact on the gas industry's research program.

Need for a Viable Fuel Cell Research Program

With falling world oil prices now providing a "window of opportunity" to develop alternative domestic energy systems such as the fuel cell power plant, it is essential that the federal government not terminate its long-term research programs in phosphoric acid and advanced fuel cell systems. The most feasible approach to commercializing these highly efficient, nonpolluting, versatile, and reliable power plants is through a continuation of jointly

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cofunded research programs with the electric and gas utilities. It is not prudent federal research policy to terminate the DOE research program in phosphoric acid fuel cells after the tremendous investment in these systems over the past eight years, especially now that a logical conclusion to the research efforts is only two or three years away. At the same time, the drastic reduction in molten carbonate and advanced fuel cell systems research funding proposed by DOE for FY 1987 is extremely shortsighted.

Obviously, with the very large federal deficit and the goals of the Gramm-Rudman Act requiring a reduction in federal expenditures, we must be sure all R&D funds are wise investments in America's future. Research funding (at a reduced level from the FY 1986 appropriated levels) for fuel cell power plant development is certainly a wise investment. Congress has recognized the importance of this research and fuel cells' potential to make a significant contribution to the U.S. energy future. It has acted accordingly when considering the DOE budget request for FY 1985 and FY 1986. Appropriations for fuel cell research in DOE for FY 1985 were $40.5 million, and in FY 1986 Congress added $26 million to the DOE budget request to continue cost-shared research projects with industry. Despite these very specific actions in support of a continuing and viable DOE fuel cell research program, the DOE FY 1987 budget request contains a total of only $5 million for all fuel cell research and also proposes to defer $22 million of the $26 million Congress added this past year. These deferrals would cause the abrupt termination of major ongoing cost-shared research projects with GRI, EPRI, equipment manufacturers, and participating utilities.

GRI recommends the following specific congressional budget actions to ensure a viable joint federal government/industry fuel cell research and development program. These recommendations are totally consistent with recent congressional actions on the DOE budget and the goals of the Gramm-Rudman Act.

1. Deny the DOE request to defer $22 million of FY 1986 appropriated funds for fuel cell research.

2. Increase the DOE FY 1987 fuel cell budget to a total of $25 million, which is a 27 percent reduction from the FY 1986 congressionally approved funding level. GRI's recommended breakdown for the funding is:

Phosphoric Acid Technology Development	$10 million
Molten Carbonate System Research	10 million
Advanced Concepts	5 million
Total	$25 million

This reduced program funding combined with funds from industry, EPRI, and GRI will allow the nation to pursue a viable fuel cell research program in the orderly fashion necessary to commercialize phosphoric acid systems by 1990 and the advanced systems in the mid- to late 1990s.

S. 1686 and S. 1687

Another important congressional initiative that would greatly assist in fuel cell development and commercialization would be to pass legislation implementing the goals of S. 1686 and S. 1687. Specifically, legislation that would accomplish the following would remove many of the legislative and

regulatory barriers to early commercialization of phosphoric acid fuel cell energy systems.

1. Amend PURPA to expand the definition of the term "cogeneration facility" to include facilities utilizing fuel cell systems.

2. Amend the Energy Policy and Conservation Act to expand the definition of the term "domestic renewable energy industry" to include industries using fuel cell technology.

3. Instruct EPA to prepare guidelines for cities and municipalities specifying environmental and safety standards for use of fuel cell technology.

4. Instruct the Secretary of Commerce to assess and report to Congress regarding export market potential for integrated fuel cell systems.

History

A fuel cell power plant is a cogeneration system that reforms natural gas to hydrogen and reacts the hydrogen gas with oxygen from the air using an electrochemical process to produce electricity, heat, and water. Installed onsite at a multifamily residential, commercial, or light-industrial building, the fuel cell power plant can supply all or part of the electrical and heating requirements of the building, often using less gas than was previously used just for heating. This is accomplished using one fuel source and with very high overall energy efficiencies, good reliability, low noise, and virtually no pollutants.

The concept of producing electricity directly by an electrochemical reaction has been known for well over a century. In the early 1960s, the U.S. National Aeronautics and Space Administration adopted the fuel cell as an on-board power source for manned space missions. Although these systems were efficient and reliable, the technology was much too expensive for general use on the ground. In the mid-1960s, the gas industry recognized the potential benefits of fuel cell technology and initiated the development of fuel cell power plants for residential and commercial use. Based on this earlier work, GRI pursued a joint R&D effort with DOE starting in the late 1970s that included a substantial field test of prototype systems and a parallel technology development program to improve the fuel cell system's reliability and to lower their costs. This technology progressed to the point where in the early 1980s extensive field test experience was required to determine the system's ability to operate effectively in a real-world environment. Research was initiated to develop the technology basis for a cost-effective, early-entry phosphoric acid fuel cell system with higher output (in the several hundred kilowatt range). Improvements that could reduce first cost and improve reliability and maintainability were in such areas as cell power density, cell stack cooler arrays, catalyst material, electrolyte management, and inverter efficiency. Use of commercially available heat exchangers and other components could also help reduce cost. The challenge has been to develop the technology base upon which the manufacturer could design, develop, and produce a unit with low production costs that still delivers required performance. The goal of the ongoing onsite fuel cell program is to provide the gas industry the opportunity to evaluate a technology and an energy service concept that could provide substantial benefits to the ratepayer.

Accomplishments

From the early stages of the onsite fuel cell program, GRI worked with the g industry and the federal government through cofunding agreements with the Department of Energy. The early work resulted in the development of a 40-kW Engineering Development Model which was laboratory tested in 1980 and 1981. In addition, Underwriters Laboratories conducted tests for preliminary system verification and safety. Consequently, fabrication of three 40-kW experimental phosphoric acid fuel cell power plants was completed and testin of these units in Oregon and Connecticut was initiated in 1982. The pre-field-test experimental units were operated through 1983, achieving a combined cumulative operational time of more than 5900 hours. Finally, in late 1983 extensive field testing began with the first of 46 test units. Field testing will be completed on all 46 units within the next few months.

As of December 31, 1985, the status of the field testing was as follows:

TABLE I

Parameter	Achieved
Number of power plants delivered:	46
Total cumulative hours of operation (all power plants combined):	241,344
Average Fleet Unadjusted Availability	63%
Longest Continuous Uninterrupted Run	90 days (2165 hours)
Number of Power Plants Experiencing Continuous Runs of at Least 1000 Hours	36

EXHIBIT A

FIELD TEST HOSTS

GRI will support the completion of the ongoing major field test for the 40-kW phosphoric acid fuel cell power plant that participating utilities are conducting. (See Exhibit A for participating utilities and location of field test units.) This effort, pursued in parallel with technology development activities to enhance system performance and reduce cost under the joint DOE/GRI cofunded project, is expected to form the basis for an initial commercial offering of phosphoric acid fuel cell systems by the manufacturer (IFC) in 1986. With the acceptance of this offer, the formulation of the power plant specification, and the placement of orders for an initial lot of power plants by the utilities, the manufacturer would complete the detailed design of the power plant and the preparation of manufacturing facilities required to ensure delivery of initial units in the 1989-1991 time frame. Utilities would use these initial units to conduct a market test of the onsite fuel cell equipment; additional follow-on orders would make possible the continuous production of power plants needed to further reduce the cost of the units. GRI support of additional technical development in 1986-1988 is also planned. This research will further advance the technology base to ensure both performance and cost levels judged crucial to the commercial viability of the initial-venture system and to broaden participation by the gas industry in the introduction of fuel cell systems. The need for a continuing base technology phosphoric acid fuel cell research program is required to complete the final phases of the program leading to the manufacturer's commercializing a fuel cell power plant.

The near-term strategy for onsite phosphoric acid fuel cell development is to simultaneously: (1) complete the 40-kW unit field test to demonstrate field verification of technical performance, maintenance characteristics, and installation requirements; (2) develop phosphoric acid fuel cell technology to a point where its application can be implemented at an acceptable price; and (3) coordinate the development and communication of user and manufacturer requirements that will define the early-entry fuel cell unit.

The design of the specific early-entry unit--size, cost, and operating characteristics--will result from the dialog between the manufacturer and the utilities interested in purchasing units for initial commercial service.

Funding

Financial participation was a cooperative effort from the beginning of the 40-kW onsite phosphoric acid fuel cell program with the gas industry, the federal government (DOE), and GRI all contributing to the field testing effort.

In 1982, the gas industry and GRI made a major commitment and significantly increased funding for onsite phosphoric acid fuel cell systems to offset the loss of DOE funds for near term research. GRI totally assumed the remaining costs of the joint DOE/GRI program to field test the 46 phosphoric acid fuel cell units. This resulted in GRI's assuming approximately two-thirds and DOE's assuming approximately one-third of the total costs for the entire field test project. A separate four-year parallel technology development program was initiated in late 1982 under a 50-50 cofunded joint effort with DOE and GRI for the purpose of increasing reliability and lowering the costs of the fuel cell system. DOE and GRI each committed to funding approximately $20 million for research with the manufacturer, United Technologies

Corporation. Congress appropriated $6 million in FY 1986 for the last phase of DOE funding. It is critical that these funds be available to complete the joint research effort.

The funding history of the onsite phosphoric acid fuel cell program over the past nine years is outlined in the following table:

TABLE II

FUNDING PROFILE
40-kW PHOSPHORIC ACID FUEL CELL PROGRAM
1978-1986
($ Millions)

	1986	1985	1984	1983	1982	1981	1980	1979	1978	Total
GRI	5.50	4.55	19.05	19.55	11.35	4.70	2.27	1.54	.69	69.20
DOE	4.61	5.21	3.73	1.50	2.00	12.00	10.85	7.40	7.30	54.60
Industry	0	3.40	4.00	8.60	8.00	6.00	3.50	1.00	.50	35.00
Total	10.11	13.16	26.78	29.65	21.35	22.70	16.62	9.94	8.49	158.80

Coordination

To date, many organizations have made significant commitments to phosphoric acid fuel cell development, including DOE, NASA, the Department of Defense, and EPRI. All are members, with GRI, of an ad hoc National Fuel Cell Coordinating Group. This group coordinates fuel cell technology development and program activities at the national level. Several other organizations also are active supporters of fuel cell research including Niagara Mohawk Power Corporation, the New York State Energy Research and Development Authority (NYSERDA), Southern California Edison, and Pacific Gas and Electric Company.

Future GRI Fuel Cell Activities

GRI will provide funds to initiate the final phases of technology development and performance verification of the onsite phosphoric acid fuel cell system in 1986-1988. This effort needs to be supplemented by a base technology program in DOE. Also, during 1986 GRI will expand and refocus its R&D to include advanced fuel cell concepts that offer advantages over the phosphoric acid type. Although phosphoric acid fuel cells show considerable promise for use in commercial, multifamily-residential, and light-industrial applications, their use is limited in industrial and absorption cooling applications that require higher-quality thermal energy. Advanced fuel cells operate at a higher temperature than phosphoric acid fuel cells (1300°F to 2000°F vs. 400°F) and, therefore, can provide higher-quality thermal energy. In addition, advanced fuel cells can achieve electrical efficiencies in the range of 45 to 63 percent, compared with 36 to 40 percent for phosphoric acid fuel cells (based on the higher heating value of natural gas). Assuming advanced fuel cells were available in a range of sizes up to several megawatts for use in appropriate commercial and industrial markets, they could yield substantial energy savings for end users and displace imported oil with domestic natural gas.

Two types of advanced fuels cells appear promising: the solid oxide fuel cell and the molten carbonate fuel cell. Although development of molten carbonate fuel cells is more advanced than solid oxide systems, major development efforts are needed in the cell stack area (power section) before the molten carbonate fuel cell can be commercialized. These include activities that have long development times and represent major technological hurdles: cathode solubility, electrolyte loss, corrosion, and thermal cycling. Only after these issues are sufficiently addressed can detailed system development begin.

Major development efforts are also required before the solid oxide fuel cell system can be commercialized. These include cell fabrication, electrical interconnect, thermal cycling, internal electrical losses, scale-up, system component integration, direct methane use, and heat recovery. These issues must be resolved before solid oxide fuel cell system development can be undertaken.

DOE and EPRI are providing separate funding for technology development leading to the demonstration of molten carbonate fuel cell systems fueled with gas from a coal gasifier. In addition, DOE is providing funding for the technology advancement of solid oxide fuel cell arrays also utilizing coal gas. However, issues specific to the use of natural-gas-fueled fuel cells as cogenerators are not being directly addressed by either organization. Because most current efforts are aimed a resolving basic cell structure and stack operation issues (such as chemical and physical stability, ancillary component development, and system integration development), they are of benefit to fuel cell systems directed at both onsite cogeneration and large central station applications.

The GRI near-term objective is to develop and monitor solid oxide fuel cell technology base activities of several geometric approaches for future system development activities and potential commercialization. To this end, GRI intends to fund parallel research of both the Westinghouse tubular concept and the Ceramatec/IFC hot-pressed, flat plate approach. GRI will continue to monitor activities conducted by Argonne under DARPA funding concerning the development of a monolithic solid oxide fuel cell. At the completion of this effort, GRI will assess the systems aspects of some of the most promising concepts.

GRI's mid-term objective is to select the most promising concept, conduct system development efforts, and reach a system proof-of-concept milestone. The mid-term efforts should prove sufficient to demonstrate the technological feasibility of the solid oxide fuel cell concept.

In the long term, GRI will conduct a field test of the system and technology development efforts. GRI believes this step is necessary to verify the technology and system developments in actual operating environments thus leading the way to a successful transfer of the technology to industry.

GRI will continue to monitor DOE and EPRI's progress in their joint program to advance molten carbonate fuel cell technology. As the carbonate stack technology progresses, GRI will reevaluate its role in adapting the technology for natural gas use.

Commercialization Potential

As mentioned earlier, a commercial offering to the gas industry of an onsite phosphoric acid fuel cell (probably in the 200-kW range) is expected in mid-1986 from IFC with delivery of the initial units planned for the 1989-1991 time frame. The commercial offering will be based on the results of the field test project, the technology development project, the ongoing dialog between IFC and the utilities, and the ability of IFC to formulate a manufacturer's consortium. Substantial progress is being made in the commercialization effort by both IFC and the gas industry. Current related activities being conducted through GRI contracts include development of a data base on building codes and standards applicable to onsite fuel cells and development of a data base of current legal and institutional issues affecting the commercialization of phosophoric acid fuel cells.

Commercialization of advanced onsite fuel cell systems, i.e., molten carbonate and solid oxide fuel cells is not expected until at least the mid-1990s. Commercialization prospects for advanced systems primarily will be within the industrial sector, whereas onsite phosophoric acid fuel cells would be marketed in the multifamily residential, commercial, and light-industrial sectors.

Summary

A viable, consistent long-term fuel cell systems research program in DOE's Fossil Energy Program is required in FY 1987 if the nation is to realize its goal of commercializing phosphoric acid fuel cell power plants by 1990. A funding level of $25 million--a reduction of 27 percent from the FY 1986 appropriated program budget--will allow critical jointly cofunded research with industry to continue and is totally consistent with past congressional action. GRI is willing to cofund with DOE on a 50-50 basis research necessary to complete the final phases of technology development and verification of the onsite phosphoric acid fuel cell system.

Senator EVANS. Thank you, very much.

Dr. Kalhammer well, to both of you, what is your judgment considering if appropriate research were to continue, it sounds to me like you are saying that commercialization is not very far away. Take 10 to 15 years, or something like the turn of the century, with commercialization at the time you suggest and with continuing research, at that point, where would you judge the life cycle costs of a fuel cell might be compared with the other more ordinary sources of electrical energy, particularly light water reactors and modern coal plant?

Dr. KALHAMMER. Mr. Chairman, we have, of course, tried to do analysis of what fuel cells would ultimately cost for quite a few years. The assumptions that we have to make is that we have a mature technology that is in mass production and that is being sold at a reasonable level, let's say, at least several hundred megawatts per year so that over a period of, say, 10 or 15 years, there would be several thousand megawatts of fuel cells sold.

Under these assumptions, our estimate is that fuel cells expressed in this year's dollars would cost approximately $800 to $1,000 per kilowatt.

Senator EVANS. That is life cycle cost, or just the capital costs?

Dr. KALHAMMER. Yes. At this capital cost, the fuel cell could compete for cycling and peaking generation and it could do so, particularly if the specific values as expressed, for instance, as a capital cost credit, for characteristics of fuel cells such as modular siting, short lead time, recovery and reuse of waste heat, higher efficiency, etcetera. If all of this were quantified, then the fuel cell should be readily competitive with other generators, whether that is in the nearer term, say, combined cycle, operating on similar fuels, or in the longer term, also with power from coal because the fuel cell can be linked to coal through the gasification or liquifaction in the longer term.

Senator EVANS. Mr. Webb, what is your view?

Mr. WEBB. Mr. Chairman, for the on-site system, he is talking about a system that is larger—the on-site of 200 to 400 kilowatts, the mature market, which I think is the one that he described, where you are talking about production line and wide applications for the year 2000, indicate that it would be $1,000 to $1,200, in current day dollars per kilowatt. The difference would be and the reason it appears to be economical to us and to our member companies is we are talking about utilizing the waste heat.

We are talking about installing these in apartment complex, where you get your electricity and maybe 60 or 70 percent of your hot water and space heating needs from this one unit. In those cases, they would be.

Now, the initial units that we are talking about trying to commercialize and our member utilities are going to be negotiating with the manufacturer, are going to be in the range of $2,200 to $2,500 per kilowatt. That clearly is not economical if you are talking about a major penetration.

There are selected markets where some of our member companies think that they can get, if you would, an early marketing entry. There is also quite a bit of potential to bring that cost down

as you get into the production line type of activity, versus test units.

Senator EVANS. Also what I was doing was attempting—I know it is a little bit of projection in imagination, but would it be accurate to say that at least current stage, the technology is well enough known and the potential for cost reduction per kilowatt, for installed kilowatt is sufficient that that curve is coming down considerably faster than the curve of continued research on such things as light water reactors, or current technology coal plants.

Mr. WEBB. Yes, sir, Senator, that is correct. Although it is not just this one technology. In nearly any new technology, you would have the same sort of scenario.

Senator EVANS. You have probably anticipated my next question: Do you think that those lines will cross, and if so, what is the real potential out there if in fact they did?

Dr. KALHAMMER. Well, I think this is a little bit of a difficult question because the cost of light water reactors, as everybody knows, has really been going up rather than down. So, the issue there is a little different. The issue is to comply in the light water field with the requirements that have been added to those that existed initially, and it was a technology that already was learned out to some extent and now a new learning has to occur in that technology. So, ultimately we certainly believe that the cost of light water reactors will come down again.

But we do feel that R&D is very much likely to reduce the cost of the phosphoric acid fuel cell because we have followed, I think, a fairly classical learning curve. We have done some analysis where we plotted how the cost of the first, let's say, 20 or so units would come down. And they do tend to follow a typical .85 learning curve. So we feel reasonably confident when we extrapolate to the numbers that I have mentioned.

But just as Mr. Webb said, the units will be significantly more expensive and that is really the point of the dilemma.

Senator EVANS. Do you have any comment at all on the fact that, you do say the light water reactors' prices are tending to go up, or at least they are not going down any, yet the Department of Energy has a several hundred million dollar continuing research program they have produced for 1987 on reactor research and development and they want to totally eliminate virtually continued development of fuel cells. Does that make any sense?

Dr. KALHAMMER. I am probably getting a little bit outside my field here, but I will repeat the statement that I just made a moment ago. I do believe that this cost escalation that we have had of light water reactors can also be ultimately reversed and put on a downward trend again through technological learning and improvement.

So, I would feel that that kind of work is certainly justified. One of the nice things about fuel cells as a small technology is that its development and demonstration is relatively inexpensive. So we feel that here is a special opportunity to bring a technology all the way to commercial fruition that is not going to take huge budgets.

Senator EVANS. Senator Ford.

Senator FORD. Doctor, you made a statement or point in your opening statement, I believe the word was "realistic." We have a realistic opportunity to bring the cells on board.

Would you elaborate on realistic just a little bit for me? Because we find so many things where it is 10 ot 20 years off—that sort of thing. So elaborate just a little bit on realistic for me, please, sir.

Dr. KALHAMMER. Yes, Senator Ford. I think the word realism comes to mind when you look at the track record that we have had in fuel cell development. When the idea first emerged that fuel cells might be practical for terrestrial power generation on utility scale, rather than just for space power, we were at a point where the cost per kilowatt of capacity might have been $100,000, and where the life of these very expensive and elaborate machines could be counted, let's say, in the hundreds or at best thousands of hours. And, over the last 12 years, in the development effort that was a true national effort, and still is, we have gone from these levels to levels where we could say today we are probably at $1,500 to $3,000 per kilowatt for the very first early units, which are still semi-custom manufactured and where the life that we have seen in large scale laboratory testing of full-size stacks can now be counted in the ten-thousands of hours.

So we are really essentially within reach, within a factor of two or three of what is needed commercially. We have gone a much longer distance in the 12 years past. So I think it is realistic, together with the envisioning of the programs that we see on the table today, to postulate that we will be home with a fully commercial technology in say three to five years at the most.

Senator FORD. Mr. Webb, you said in your statement that GRI had entered into a contract in 1982 for the expense, and I guess it is equal expressing—how long was that contract? Was that just year to year, or was that a long-term contract with GRI putting up money and knowing it is going to have to carry for a long period of time? Just what kind of understanding did you have when you entered into the contract in 1982.

Mr. WEBB. Senator Ford, our understanding when we entered into the contract was two-fold. One, we agreed to increase our budget in our own program up to a level about $20 million, to totally assume the cost of the field test.

Senator FORD. How much is the field test? How much would that be of the $20 million?

Mr. WEBB. The total cost of the field test, GRI will have put in about $37 million, member utilities will put in $35 million and DOE will have put in about $15 million prior to 1982.

OK. The other program which was a 4-year program, at about $20 million from GRI and the Department of Energy to do the technology development that was to go along and parallel, to look at things that we would learn in the field test to bring the cost of these initial units down.

It is a Government contract and all government contracts stipulate that it is subject to appropriations, etcetera. But our understanding and the plan, really, was a 4-year program to carry us through this technology development phase.

Senator FORD. You would be led to believe, then, with the present budget, when it was finally decided on through continuing resolution, that you were home free for fiscal 1986?

Mr. WEBB. Yes, sir. That is correct.

Senator FORD. Now you are getting a deferral.

Mr. WEBB. Yes, sir. They told us that the funds would be cut off on March 20 of this year. The problem is we have our money committed. We have half of the money for this particular year of the program; NASA is managing the program jointly for the Department of Energy, our utilities, and GRI. Our part of the money is committed there. We also have the rest of our fuel cell money to finish the field test activities.

It is a catch-22. If we stop the field test activities, then the utility involvement tapers off, which is critical to commercializing it; if DOE pulls out their funding on the 20th, then we don't finish up with the technology development so the manufacturer can make a commercial offering.

Senator FORD. Has DOE told you that they will give you the money next year?

Mr. WEBB. No, sir, Senator. My understanding is that the money would be deferred to offset new budget authority in other areas in the Department of Energy's budget.

Senator FORD. Mr. Chairman, that is exactly what we understood from the gentleman previously. Here is a contract that was entered into in good faith, I hope by both sides, and now we find that we are on the verge of—a Democrat once said he could touch it with his fingernails—that it is being deferred and actually the indication is they will not go on in this arena, the money will be used in others.

I have just one further question. Mr. Webb, did I understand you to say that if this program were eliminated and for all practical purposes, it is being terminated, that industry concensus is that the consumer or the taxpayer is really the loser because you are almost there?

Mr. WEBB. Yes, sir, Senator. I don't think you can find another program at the Department of Energy, like the phosphoric fuel cell, where you have two major utility organizations putting up their own money; we have brought 31 of our member companies, and they put up their money at risk—they have to recover after the fact in rate cases before the commission. Where you have that kind of utility participation cofunding—in our case, the cofunding is nearly 2-to-1, and then when you say you are 2 or 3 years away because it is now too near term and the technology is too mature, we ought to go to the more long-range systems—I don't see how the taxpayer ever gets any payback on the research dollar if that is the attitude of the administration.

Senator FORD. Let me put a last (b), would the new, far-range research and development cost less than the finalization of this particular fuel cell? Is that the budget projection, that if you go into far-term, you need just put a little in it and not put in say the $25 million you are recommending?

I may not be making my point right, but where we are deferring $22 million and only recommending $5 million the next fiscal year, and that $17 million will go into new research and development,

new ideas, far-reaching—another 10, 15, 20 years—would that cost less then to get into that arena than it would be to finish up this one?

Mr. WEBB. Yes, sir, Senator. Because you can always make a case that a technology that has no chance to be developed before, say, 1998 to the 2000 timeframe, that you can stretch the pace of the program. When you have the private sector involved within their own dollars and you get closer to commercialization, obviously the costs increases.

It just that in this case, the utilities, not only the gas industry, but the electric industry, have put in more than twice as many dollars to try to do the near term activity under the assumption that the Government would shift into the more long-term. So, I guess my concern really is, obviously what will happen if DOE terminates the program, and that is what they are planning to do—they are planning to terminate all phosphoric acid fuel cell work, we won't get a commercial offering this summer from the manufacturer.

The manufacturer, rightly so, will say the technology development program hasn't been completed. Now, then in our application next year to the Federal Energy Regulatory Commission, we will have to try to find additional money so that we can then pick up more of that research. But the problem is, if the timeframe stretches too greatly, and the utilities have invested their own moneys, start having problem with their State regulatory commissions on being allowed to recover their money, their funds, in rate cases because there is no used and useful product that is going to be produced in a reasonable timeframe—It really is a catch-22, Senator.

Senator FORD. Mr. Chairman, I find this to be so true and it is becoming obvious, we have never completed anything. We get right up to where we can touch it and move on with it, and we don't complete it. Then we get into a far-reaching, 15-20-25-year program out here, and we start nickeling and diming it to death.

I have said early on, let's build something, even if it is a white elephant, you know, and it doesn't work. Let's try to complete something instead of getting into all things things, everybody is excited about, and then, poof, it is gone.

And when really leave the consumer and the taxpayer hanging out there, the industry that has invested more money than the taxpayer, or Government, basically, by several times, and the basements that have grown to laboratories—You know, start in the basement with an idea, and somehow or another we just don't complete it.

I wish there was some way we could get to this and just say—put our hand on it. Say that we have done it, it has been completed, it works. The taxpayer is going to benefit by it; the utility out there has put up its money—31 of them that you are talking about. They would say, we have finally completed a research and development program; it is realistic, as the doctor says, that it can be brought on line; it has been tested.

I would like to fight for this one, Mr. Chairman, if we could, somewhere along the line. I know that we are going up against major odds and my name is not David, but let's see if we can't try

it. I hope that we can and I thank you gentlemen for your very wise and comforting testimony this morning.

Senator EVANS. I share your remarks. It is very much like running the Indy 500 and when you get to the last fuel stop, you pull into the DOE pit and they say, "We are out of gas." That is a hell of a way to lose a race.

Senator Matsunaga.

Senator MATSUNAGA. Mr. Chairman, I have no questions. But I would like to commend the two gentlemen, Dr. Kalhammer and Mr. Webb, for their testimony. I am sure they will weigh heavily in the formulation of the decision by members of this subcommittee, and the full committee to report the two bills out favorably.

Dr. KALHAMMER. Thank you, Senator.

Mr. WEBB. Thank you, Senator.

Senator EVANS. Thank you both, very much. We may have a couple of other questions, if we could submit them to you in writing, to expand on some of your remarks. You have been very, very helpful and we appreciate it.

Panel II, Ted Light, general manager, governmental affairs, Public Service Electric & Gas Company for Fuel Cells Users Group, and Malcolm Jones, Ebasco Inc. for Industrial Fuel Cells Association.

This panel is to represent the potential or presumably current users of fuel cells. Let's start with Mr. Light. You are first on the list here.

STATEMENT OF TED H. LIGHT, GENERAL MANAGER, GOVERNMENT AFFAIRS, PUBLIC SERVICE ELECTRIC & GAS CO., NEWARK, NJ, ON BEHALF OF THE FUEL CELLS USERS GROUP OF THE ELECTRIC UTILITY INDUSTRY, INC.

Mr. LIGHT. Thank you, Mr. Chairman. My name is Ted Light. I am general manager of governmental affairs for Public Service Electric & Gas Company of Newark, NJ.

I am here today to speak about the status of fuel cell technology and the opportunity for its commercialization because my company has been supporting the development of this technology for nearly 20 years. Our company was one of nine electric utilities who joined with United Technologies Corp. to develop the multimegawatt fuel cell power plants and test the 1 megawatt demonstration unit in the mid-1970's. Our company has continued to support the development of this technology with both financial and manpower resources and is considering being one of the first purchasers of the commercial power plants now being developed.

I am also here to speak on behalf of the Fuel Cell Users Group of the Electric Utility Industry. The Fuel Cell Users Group is an organization of 55 electric utilities, including the national trade associations of the electric power industry: The American Public Power Association, National Rural Electric Cooperative Association, and the Edison Electric Institute.

The Users Group was established in 1980 to assist, promote and accelerate the development and electrical application of phosphoric acid fuel cell technology. And, also here with me today is Mr. Jeff Surface, who is the executive director of the Fuel Cell Users Group.

The Fuel Cell Users Group and my remarks today are focused solely on the development and application of phosphoric acid multimegawatt fuel cell technology. Our company has also been active participant in the gas industry's on-site 40 kilowatt program, including the testing of two of the 40-plus units being operated throughout the country. We also have an interest in the long-term potential of molten carbonate and solid oxide technologies. It is the multmegawatt phosphoric acid technology, however, that offers to the electric utilities the early promise of a clean, modular, efficient electrochemical generation technology for siting and operation in urban locations and remote applications, as well.

Before I offer our comments on Senate bills 1686 and 1687, I would like to discuss the status of commercialization of this technology, the importance of the Federal role today and the harm that deferrals and other discontinuities in the Federal support mean to this important development effort.

The Users Group's Management Committee, on which I sit, has periodically reviewed in depth the development programs and commercialization plans of both International Fuel Cells Corp. and the Westinghouse Electric Corp. Having recently reviewed the Westinghouse program, we concluded that the revised effort which now includes the testing of a 1.5 megawatt pilot plant is appropriate and warrants our support.

The International Fuel Cells Program is now facing the difficult challenge of the marketplace, acceptance of commercial scale design and pre-commercial terms and conditions by our industry, the utility consumers. My remarks deal primarily with this challenge and the importance of an advanced technology effort in the phosphoric acid fuel cells.

For many years, the developers, the electric utility industry and the Federal Government, have been promising that fuel cell technology will soon be commercial. There are times when many of us have been questioned whether the real commercialization of this technology would ever be achieved. I am here today not to tell you that this has now been achieved, but that we are at a very important crossroads.

The leading U.S. developer of this technology, International Fuel Cells Corp., has now placed before the electric utility industry a commercial-scale offering that marks the beginning of commercialization. The significance of this event cannot be overstated since acceptance of this offer is likely to initiate the production of the first commercial-scale fuel cell powerplants for electric utility application.

Acceptance of the IFC's proposal will indicate the utility industry's willingness to make the substantial investments that this offer requires. Optimism will only be warranted as individual utilities make commitments which collectively launch the commercial application of this technology.

The utility industry, I believe, will support this initial commercialization effort because the development of this technology is important to us. However, I would like to underscore the fact that the results of today's technology development efforts will yield only marginal, economic applications, except for certain situations.

What I mean is that there are urban applications, like in our service territory in New Jersey and at other constrained locations, where the fuel cell with its environmental characteristics will be clearly an advantageous technology.

To obtain widespread application of this technology, however, it will be necessary to meet lower capital costs and improve efficiency objectives with acceptable reliability that will yield a generator useful to large segments of the industry.

My utility is currently evaluating this commercial and technical status of this technology and I cannot yet predict the outcome of this internal review. Speaking more generally, however, I would suggest that many utilities like ours will find suitable, economic applications of this technology to afford the higher costs of some of the earlier commercial units.

We will pay higher costs because in certain applications they are justified, and also because we believe the technology has the potential of even lower capital costs and higher efficiencies than are now attainable if the successes of the past joint Government/private cooperation can be continued.

Our industry will make these private investments only if there is a continuing, concurrent, advanced, phosphoric acid technology development program that will allow this capability to be reached. Since all available resources of the developer are being invested to engineer these early market units with today's technology, and to develop the necessary manufacturing capability for this early market program, and since the utility resources will be invested to purchase, install, and operate these early units, the resources for a development program that will yield breakthroughs in efficiency and capital costs must come from other sources.

The advantages of this technology accrue to the public, not the electric utilities themselves. The benefits of this improved technology accrue to the utility ratepayers and the beneficiaries of the environmental improvement.

Particularly in today's regulatory climate, the utility is not rewarded for taking on the risks of new technology. They are more likely to be penalized. We believe that the investments being made by the developers and the utilities must be complemented by public support aimed at significant technological breakthroughs that will offer an even greater promise for the technology in the future.

The Fuel Cell Users Group, therefore, supports the Senate bill 1686, the Renewable Energy/Fuel Cell Systems Integration Act of 1985, since this bill proposes research and development that will broaden the application of this technology. We further support the use of Clean Coal Technology Program funding for the application of fuel cells with coal gasification. The clean use of coal can be achieved through its use with this environmentally benign generating technology.

We have reason to believe that significant cost reduction in the stacks and even greater efficiency in the individual powerplant components can be achieved by a newly focused technology development program. With achievement of these objectives and continued improvement in reliability, this technology can achieve widespread application beyond that which would be achievable in today's technology.

We realize that the current Federal budget deficit requires a belt tightening that we will all feel. Recognizing that, it is important that the Department of Energy and Congress understand the utility industry's commitment to and interest in this technology. We have, therefore, initiated a dialog to avoid any misunderstanding. The significant membership in the Fuel Cell Users Group and the continuing commitment by many individual utilities to the development of this technology are evidence of the historical interest.

We have initiated with the Electric Power Research Institute a revised study of the market for this technology, as mentioned previously by Dr. Kalhammer, and we will share the results of this with the Department of Energy and with Congress. We are intending that this be a realistic assessment, not one which paints an unrealistically rosy picture.

We have opened the users group management committee meetings to the Department of Energy personnel to improve their understanding of our commitment. We have offered to continue to update DOE personnel with respect to the utility response to the IFC offer and Westinghouse activities.

This is not an easy time to try to commercialize a technology in the electric utility industry given the large reserve margins, declining fuel costs, uncertain load growth, and the financial pressures of completing large construction programs. Despite these events, however, we believe the commercialization of this technology can be successful because it is so important to many utilities in the United States.

I would like to close by saying that the Fuel Cell Users Group supports legislation which seeks to improve fuel cell technology or to widen its application. We support Senate bill 1686, the Renewable Energy/Fuel Cell Systems Integration Act of 1985, and most portions of Senate bill 1687, the Fuel Cell Energy Utilization Act of 1985.

The change to PURPA should be considered with a review of the total PURPA program.

Mr. Chairman, in commenting on the need for Federal moneys for the development of this technology, I should note that the program of the Westinghouse Electric Corp. also offers significant promise for industry. I have not dwelled on this program because its technology development agenda is so clearly defined and understood by both the Federal and private communities and does not yet present the same commercialization opportunities.

We do, however, support funding of both technology development efforts in the hopes that phosphoric acid fuel cell technology will be available from one or more domestic U.S. suppliers in the near future and will be widely applicable throughout the industry in the 1990's.

Mr. Chairman, I thank you and the committee for your interest in this attractive technology. I encourage your continued support and will be happy to try to answer any questions that you may have.

[The prepared statement of Mr. Light follows:]

STATEMENT ON SENATE BILLS
S. 1686 and S. 1687, and
FUEL CELL RESEARCH, DEVELOPMENT
AND COMMERCIALIZATION

Presented to the

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

to the

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

Ted H. Light

General Manager, Government Affairs

Public Service Electric & Gas Company

Newark, New Jersey

on behalf of the

FUEL CELL USERS GROUP OF THE ELECTRIC UTILITY INDUSTRY, INC.

February 24, 1986

Mr. Chairman, I am Ted Light, General Manager of Government Affairs for Public Service Electric & Gas Company of Newark, New Jersey. I am here today to speak about the status of fuel cell technology development and the opportunity for its commercialization because my company has been supporting the development of this technology for nearly 20 years. Our company was one of nine electric utilities who joined with United Technologies Corporation to develop multimegawatt fuel cell power plants and test a one megawatt demonstration unit in the mid-1970's. Our company has continued to support the development of this technology, with both financial and manpower resources, and is considering being one of the first purchasers of the commercial power plants now being developed.

I am also here to speak on behalf of the Fuel Cell Users Group of the Electric Utility Industry, Inc. The Fuel Cell Users Group is an organization of 55 electric utilities including the national trade associations of the electric power industry: The American Public Power Association, National Rural Electric Cooperative Association, and the Edison Electric Institute. The Users Group was established in 1980 to assist, promote and accelerate the development and electric utility application of phosphoric acid fuel cell technology.[1]

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[1]The Fuel Cell Users Group of the Electric Utility Industry, Inc., is a five-year old organization with a membership of 55 utilities (and 10 associate members) spanning the privately, publicly, and cooperatively owned electric utility industry. A list of the membership is included as Attachment 1. Cumulatively, the members of the Users Group represent about 40 percent of the U.S. generating capacity. The Group is united in the interest of encouraging and supporting research, development, and demonstration leading to the ultimate commercialization of the phosphoric acid fuel cell power plant.

The Fuel Cell Users Group, and my remarks today, are focused solely on the development and application of phosphoric acid, multi-megawatt fuel cell technology. Our company has also been an active participant in the gas industry's on-site 40 kW program including the testing of two of the 40+ units being operated throughout the country. We also have an interest in the long term potential of molten carbonate and solid oxide technologies. It is the multi-megawatt phosphoric acid technology, however, that offers to electric utilities the early promise of a clean, modular, efficient electrochemical generation technology for siting and operation in urban locations and remote applications as well.

Before I offer our comments on Senate Bills 1686 and 1687, I would like to discuss the status of commercialization of this technology, the importance of the federal role today and the harm that deferrals and other discontinuities in the federal support mean to this important development effort.

The Users Group's Management Committee on which I sit, has periodically reviewed, in depth, the development programs and commercialization plans of both International Fuel Cells Corporation and Westinghouse Electric Corporation. Having recently reviewed the Westinghouse program, we concluded that the revised effort which now includes the testing of a 1.5 MW pilot plant is appropriate and warrants our support. The International Fuel Cells program, is now facing the difficult challenge of the market place - acceptance of commercial scale design and pre-commercial terms and conditions by our industry, the utility consumers.

My remarks deal primarily with this challenge and the importance of an advanced technology effort in phosphoric acid fuel cells.

For many years, the developers, the electric utility industry and the federal government have been promising that fuel cell technology will soon be commercial. There are times when many of us have been questioned whether real commercialization of this technology would ever be achieved. I am here, today not to tell you that it has now been achieved, but that we are at a very important crossroads. The leading U.S. developer of this technology, International Fuel Cells Corporation has now placed before the electric utility industry a commercial scale offering that marks the beginning of commercialization. The significance of this event cannot be overstated, since acceptance of this offer is likely to initiate production of the first commercial scale fuel cell power plants for electric utility application. Acceptance of IFC's proposal will indicate the utility industry's willingness to make the substantial investments that this offer requires. Optimism will only be warranted as individual utilities make commitments which collectively launch the commercial application of this technology.

The utility industry, I believe, will support this initial commercialization effort because the development of this technology is important to us. However, I would like to underscore the fact that the results of today's technology development efforts will yield only marginally economic applications, except for certain situations. What I mean is that there are urban applications, like in our service territory in New Jersey and at other

constrained locations, where the fuel cell with its environmental characteristics will be a clearly advantageous technology. To obtain wide spread application of this technology, however, it will be necessary to meet lower capital cost and improved efficiency objectives, with acceptable reliability, that will yield a generator useful to large segments of the industry.

My utility is currently evaluating the commercial and technicial status of this technology and I cannot yet predict the outcome of this internal review. Speaking more generally, however, I would suggest that many utilities like ours will find suitable economic applications of this technology to afford the higher cost of some of the early commercial units. We will pay higher costs, because in certain applications they are justified, and also because we believe the technology has the potential of even lower capital costs and higher efficiencies than are now attainable, if the successes of the past joint government/private cooperation can be continued.

Our industry will make these private investments only if there is a continuing concurrent advanced phosphoric acid technology development program that will allow this capability to be reached. Since all available resources of the developer are being invested to engineer these early market units with today's technology, and to develop the necessary manufacturing capability for this early market program, and since the utility resources will be invested to purchase, install and operate these early market units, the resources for a development program that will yield breakthroughs in efficiency and capital costs must come from other sources.

The advantages of this technology primarily accrue to the public, not the electric utilities themselves. The benefits of this improved technology accrue to the utility ratepayers and the beneficiaries of environmental improvement. Particularly in today's regulatory climate, the utility is not rewarded for taking on the risks of new technology - they are more likely to be penalized. We believe that the investments being made by the developers and the utilities must be complemented by public support aimed at significant technological breakthroughs that will offer an even greater promise for the technology in the future.

The Fuel Cell Users Group, therefore, supports the Senate Bill 1686, the "Renewable Energy/Fuel Cell Systems Integration Act of 1985," since this bill proposes research and development that will broaden the application of this technology. We further support the use of Clean Coal Technology Program funding for the application of fuel cells with coal gasification. The clean use of coal can be achieved through its use with this environmentally benign generating technology.

We have reason to believe that significant cost reduction in the stacks and greater efficiency in the individual power plant components can be achieved by a new focused technology development program. With achievement of these objectives and continued improvement in reliability, this technology can achieve widespread application beyond that which would be achievable with today's technology.

We realize that the current federal budget deficit requires a belt-tightening that we will all feel. Recognizing that, it is important that the Department of Energy and Congress understand

the utility industry's commitment to and interest in this technology. We have, therefore, initiated a dialogue to avoid any misunderstanding. The significant membership in the Fuel Cell Users Group and the continuing commitment by many individual utilities to the development of this technology are evidence of the historical interest. We have initiated with the Electric Power Research Institute a revised study of the market for this technology, and we will share the results with the Department of Energy and with Congress. We are intending that this be a realistic assessment, not one which paints an unrealistically rosy picture. We have opened the Users Group Management Committee meetings to Department of Energy personnel to improve their understanding of our commitment. We have offered to continue to update DOE personnel with respect to the utility response to the IFC offer and Westinghouse activities.

This is not an easy time to try to commercialize a technology in the electric utility industry given the large reserve margins, declining fuel costs, uncertain load growth and the financial pressures of completing large construction programs. Despite these events, we believe commercialization of this technology can be successful because it is so important to many utilities in the United States.

I would like to close by saying that the Fuel Cell Users Group supports legislation which seeks to improve fuel cell technology or to widen its application. We support Senate Bill 1686, the "Renewable Energy/Fuel Cell Systems Integration Act of 1985" and most portions of Senate Bill 1687, the "Fuel Cell Energy

Utilization Act of 1985." The change to PURPA should be considered with a review of the total PURPA program.

Mr. Chairman, in commenting on the need for federal monies for development of this technology, I should note that the program of the Westinghouse Electric Corporation also offers significant promise for the industry. I have not dwelled on this program because its technology development agenda is clearly defined and understood by both the federal and private communities and does not yet present the same commercialization opportunities. We do, however, support the funding of both technology development efforts in the hopes that phosphoric acid fuel cell technology will be available from one or more domestic U.S. suppliers in the near future and will be widely applicable throughout the industry in the 1990's.

Mr. Chairman, I thank you and the Committee for your interest in this attractive technology. I encourage your continued support. I will be happy to respond to any questions or comments on my remarks.

Senator EVANS. Thank you, Mr. Light.
Mr. Jones.

STATEMENT OF MALCOLM S. JONES, JR., EBASCO SERVICES, INC., ON BEHALF OF THE INDUSTRIAL FUEL CELLS ASSOCIATION

Mr. JONES. I am Malcolm Jones of Ebasco Services Corp., and project manager of our office in Santa Ana, CA. I am appearing here today as president of the Industrial Fuel Cell Association [IFCA] to comment on the fiscal year 1987 fuel cell budget of the Department of Energy.

The Industrial Fuel Cell Association is 3 years old and how has over 34 corporate and association members. Incorporated in 1984, IFCA is a not-for-profit industry trade association expressly directed toward all aspects of employing fuel cells in the industrial sector. Our members represent a wide spectrum of interest, from heavy industries such as aluminum, chemicals, and petrochemicals, organizations that manufacture fuel cells and their components, construction companies, and consulting organizations. Our purpose is to promote, educate, and encourage the development, purchase, and use of fuel cells in the industrial sector.

It is not generally recognized that there are potentially large markets for fuel cell systems for other than electric utility or gas utility applications, which we have heard a lot about today. A number of studies have shown a potentially large market for fuel cell systems of several different types for the industrial cogeneration in many industries.

In addition to the cogeneration market, studies have shown that there can be very large markets for fuel cell systems in the transportation industry. As a resident of southern California, I frequently can look out my window to a layer of smog which is accumulating and know that the fuel cell industry is one of the most viable, nonpolluting alternatives to the internal combustion engine for transportation applications, and through the use of fuel cell systems, most of the nitrogen oxides now emitted by cars, trucks, and trains could be eliminated.

As an indication of the magnitude of the market for fuel cells in just one industrial sector, IFCA performed a market study survey of the chlor-alkali industry. The survey asked the following questions of manufacturers in the chlor-alkali industry:

The likely size of fuel cell; the probable size of the markets; characteristics of the systems needed; uses for the cogenerated steam, and the desired steam pressure; the energy systems which will be competing with fuel cells; institutional factors which could encourage fuel cells.

Questionnaires were sent to companies representing 45 separate chlor-alkali plants and replied have been received which represented 49 percent of the U.S. total capacity.

The respondents predicted that by the year 2000, fuel cell capacity in their plants could reach approximately 25 to 40 percent of the existing electrical demand. This would translate into 900 to 1,500 megawatts for the entire chlor-alkali industry.

We recently completed a study for the petroleum refining industry with similar conclusions. Details of these studies can be made available to interested parties who will contact the association.

As recent statistics bear out, our industries and economy are rebounding from the lethargic and regressive period of the 1970's. We are obviously pleased by this turn of events and at the same time, wary of several potential obstacles in a sustained growth period. Specifically, our country appears to forgotten about the energy crisis.

Twice this ugly monster reared its head during the 1970's, and twice, our national response was inadequate or incompetent. Since those trying times, our energy posture has improved, but for the wrong reasons. These were the economic downturn and the resulting low demand for energy.

We are now approaching, once again, a period where an increased energy demand will require new or more efficient supplies in the form of heat and power. The industrial sector, unfortunately, is not known for aggregating its cumulative support for any new technology development as a nondescript body. The high expectations for fuel cells and especially for the molten carbonate systems have forced an exception to this unusually passive stance by a very large sector of industry.

IFCA members and supporters want to see these devices successfully enter the marketplace. The promise of a 60-percent efficient electric power source, coupled with high grade, clean, waste heat available for cogeneration have attracted a lot of attention. There is a sustained hope that the hardware research efforts presently underway can meet the cost and performance levels that have been established for these technology programs.

Unlike the utility sector, industry cannot wait 15–20 years to recover the costs of an investment, nor can it afford to be without power no matter what the price. In many industries, continuity of electrical service is the primary issue when choosing a power source. On this score, the fuel cell systems have a potential to meet a wide market demand for different levels of capacity with compact units which can be located close to the load, thereby minimizing outages from transmission line failure, while retaining environmental compatibility and use a number of alternative fuels.

With this tremendous potential, individual companies are still unable to substantially contribute to the costs for R&D since the risks remaining are still formiddable, and there is no substantial return to the industrial user until the fuel cell system is available in commercial service and producing his product. Therefore, as an individual, he has little incentive himself to invest in fuel cell energy research and development.

The solid oxide fuel cell is another system which appears to be well suited for industrial cogeneration in what could be referred to as combined cycle operation. With the solid oxide technology, the operating temperatures are higher but the materials of construction are more benign than those in the molten carbonate system. The solid oxides have a capability of using a wide range of gaseous fuels. In combined cycle operations, we have relatively high efficiency.

As an indication of industry interest in fuel cell technology, of the responses to the Department of Energy's request for clean coal technology information proposals last spring, nine of the replies received proposed demonstrations of fuel cell technology. Of these, one-third were from industrial organizations. The others were from electrical utilities, and government, or people who have previously been identified as primary beneficiaries of fuel cell technology. With the ability to use all types of grades of coal or other solid fuels such as petroleum coke or biomass as a fuel, the fuel cell system is an extremely attractive option for many industrial users.

This year, as in the past, the administration has recommended dramatic reductions in this program. The amounts required to bring this technology to within industry's financial conditions amounts to a small fraction of the cost of developing one new jet engine. Yet the most revolutionary of the new power generation technologies yet conceived by our best technical brains appear very low on the list of the administration's budget priorities. Society is in debt to the Congress, and to this committee in particular, for the courage to continue including funds directed toward the advancement of fuel cells in the annual appropriations bill.

Although industrial interest is primarily in advanced systems, our association has a concern that unless the phosphoric acid program is brought to early commercialization, demonstrating that fuel cells are for real, support for the entire fuel cell program will start to slip badly. There will be nothing quite so beneficial to the fuel cell program as having an operating fuel cell plant of any type available for inspection by the industrial decisionmakers.

Once these individuals perceive that fuel cells are a viable operation for their industry or business, they will vote with their checkbooks to make the fuel cell industry take off with a high rate of applications in all industries.

For this reason, we of the Industrial Fuel Cell Association recommend that the fiscal year 1986 support be continued at least at the 1986 levels for all fuel cell programs.

We would also like to see the changes in PURPA which Senator Matsunaga recommended in his legislation.

Mr. Chairman, I want to thank you and the subcommittee for your sustained interest in this attractive energy conversion technology and request your continued to support. I will be happy to respond to any questions or comments on these remarks.

[The prepared statement of Mr. Jones follows:]

STATEMENT ON THE FY 1987 FUEL CELL BUDGET

OF THE DEPARTMENT OF ENERGY

MALCOLM S. JONES, JR.

EBASCO SERVICES, INCORPORATED

SPEAKING FOR THE INDUSTRIAL FUEL CELL ASSOCIATION

PRESENTED TO

THE ENERGY RESEARCH AND DEVELOPMENT SUBCOMMITTEE

THE SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

FEBRUARY 24, 1986

STATEMENT OF MALCOLM S. JONES, JR.

Mr. Chairman, and Members of the Subcommittee:

I am Malcolm Jones of Ebasco Services, Incorporated. I work in the Ebasco Western Regional Office in Santa Ana, California, as a Project Manager. I am appearing here today as President of the Industrial Fuel Cell Association (IFCA) to comment on the FY-1987 Fuel Cell Budget of the Department of Energy.

The Industrial Fuel Cell Association is three years old and now has over thirty four Corporate and Associate members. Incorporated in 1984, IFCA is a not-for-profit industry trade association expressly directed towards all aspects of employing fuel cells in the industrial sector. Our members represent a wide spectrum of interests - from heavy industries such as aluminum, chemicals and petrochemicals, organizations that manufacture fuel cells and their components, construction companies, and consulting organizations. Our purpose is to promote, educate, and encourage the development, purchase, and use of fuel cells in the industrial sector.

It is not generally realized that there are potentially large markets for fuel cell systems for other than electric utility or gas utility applications. A number of studies have shown a potentially large market for fuel cell systems of several different types for industrial cogeneration in many industries. Most of my present professional activities are related to the development, engineering, design, and construction of cogeneration projects. California has been one of the leading states in the nation in the development of cogeneration projects. The original goals of 2000 MW of cogeneration capacity in California by 1992 has already been surpassed. If we had a viable fuel cell industry in place, offering products for the commercial market, it is my personal belief that we could have at least doubled the number of cogeneration projects in California.

Our Ebasco office is about two miles from one of the sites where three of the On-Site demonstration units are being operated by the Southern California Gas Company. At every opportunity, I take visitors to see a real life fuel cell system in operation. The most frequent questions asked are "Where can I get one of these? " and " How much will it cost per Kilowatt?" At this point, I have to explain that no one in the United States is offering them for sale, and the inquirer could not possibly afford the the "built by hand" prototype units used in the On-Site demonstration program. The California energy regulatory agencies, both the Public Utilities Commission, and the California Energy Commission have been supportive of cogeneration. In private discussions with individuals in both organizations the most frequent question is "When will fuel cells be available for cogeneration?". The potential market for fuel cells to be used in cogeneration applications exists in California, and presumably similar markets exist in the other parts of the United States.

In addition to the cogeneration market several studies have shown that there can be a very large market for fuel cell power systems in the transportation industry. As a resident of Southern California, I frequently can look out my window at the layer of nitrogen oxides which accumulate below the inversion layer (producing what some refer to as smog) and I know that the fuel cell industry has one of the most viable, non-polluting, alternative to the internal combustion engine for transportation applications, and that through the use of fuel cell systems, most of the nitrogen oxides now emitted by cars, trucks, and trains could be eliminated.

As an indication of the magnitude of the market for fuel cells in just one industrial sector, IFCA performed a market study survey of the chlor-alkali industry. The survey asked the following questions of manufacturers in the chlor-alkali industry:

1. Likely size of fuel cell installations.

2. Probable size of the market.

3. Characteristics of the systems needed.

4. Uses for the cogenerated steam, and the desired steam pressure.

5. The energy systems which will be competing with fuel cells.

6. Institutional factors which could encourage fuel cell use.

Questionnaires were sent to companies operating 45 separate chlor-alkali plants, and replies have been received on 19 of these plants. The replies cover about 49% of total US capacity.

Conclusions:

1. The respondents predicted that by year 2000, fuel cell capacity in their plants could reach 25 to 40% of existing electrical demand. This would translate into 900-1500 MW for the entire chlor-alkali industry.

2. Individual fuel cell installations will be divided about equally between units of less than 10 MW and those in the 10-25 MW capacity range.

3. Most chlor-alkali producers would use fuel cells as a supplementary DC power source for their chlorine circuits. Thus, the fuel cell systems should be designed to supply high amperage DC electricity at 1000 volts or less.

4. Less than half the respondents have steam distribution systems that operate at pressures of 100 psig or less. A majority of the systems operate at pressures in the 150-250 psig range. The usefulness of a fuel cell system would be greatly increased if the operating temperature could be increased enough that the cogenerated steam was at 250 psig pressure.

5. Federal incentives to encourage early fuel cell installations will be moderately important in convincing the chlor-alkali industry to adopt this new technology.

6. Many plants already use the co-produced hydrogen as a fuel today, and more indicate that they would increase hydrogen use if fuel prices increase. Thus, for many chlorine producers, their by-product hydrogen is valued at its fuel value when used under a boiler.

A detailed analysis of this survey is available to interested parties who wish to contact the Association.

As recent statistics bear out, our industries and economy are rebounding from the lethargic and regressive period of the 1970's. We are obviously pleased by this turn of events, and at the same time, wary of several potential obstacles in a sustained growth period. Specifically, our country has forgotten about "the energy crisis".

Twice, this ugly monster reared its head during the 1970's, and twice, our national response was inadequate or incompetent. Since those trying times, our energy posture has improved, but for the wrong reasons. These reasons were the economic downturn and the resulting low demand for energy. We are now approaching, once again, a point where an increased energy demand will require new or more efficient supplies in the form of heat and power. The industrial sector is not known for aggregating its cumulative strength to support any new technology development as a nondescript body. The high expectation for fuel cells, and especially the molten carbonate-based systems, have forced an exception in this usually passive stance by a very large sector of industry. IFCA members and supporters want to see these devices successfully enter the marketplace. The promise of a 60% efficient electric power source, coupled to a high grade, clean, waste heat available for cogeneration have attracted a lot of attention. There is a sustained hope that the hardware research efforts presently underway can meet the cost and performance levels that have been established for these technology programs.

Unlike the utility sector, industry cannot wait 15-20 years to recover the costs of an investment. Nor can it afford to be without power, no matter what the price. In many industries, continuity of electrical service is the primary issue when choosing a power source. On this score, the fuel cell systems have the potential to meet a wide market demand for different levels of capacity with compact units which can be located close to the load, thereby, minimizing outages from transmission line failure, while retaining environmental compatibility, and use a number of alternative fuels. With this tremendous potential, individual companies are still unable to substantially contribute to the costs for the R&D since the risks remaining are still formidable, and there is no substantial return to the industrial user until the fuel cell systems are available for commercial service and used in producing his product. Therefore, as an individual, he has little incentive himself to invest in fuel cell Research and Development.

continue to advance this technology until, at least, prototype fuel cell stacks of the advanced types have been demonstrated with commercially acceptable lifetimes. There are only a few manufacturers with serious and substantial professional teams directed towards perfecting and selling generic molten carbonate systems.

The solid oxide electrolyte fuel cell is another system which appears to be well suited for industrial cogeneration in what could be referred to as combined cycle operation. With the solid oxide electrolyte technology, the operating temperatures are higher, but the materials of construction are more benign than those in the molten carbonate system. The solid oxide fuel cells have the capability of using a wide range of gaseous fuels. In combined cycle operations, the molten carbonate and solid oxide fuel cell systems represent an extremely efficient method for converting our finite and dwindling supplies of gaseous fuels and copius supplies of solid fuels to electrical energy which can be used to power a growing and more competitive U. S. economy. When compared to virtually all other new technologies on a cost/benefit basis, fuel cells are a superior federal R&D investment.

As an indication of industry interest in fuel cell technology, of the responses to the Department of Energy's request for clean coal technology information proposals last spring, nine of the replies received proposed demonstrations of fuel cell technology. Of these, one-third were from industrial organizations. The others were from electrical utilities and government or other non-industrial organizations which have previously been identified as the primary beneficiaries of fuel cell technology. With the ability to use all types and grades of coal or other solid fuels such as petroleum coke or biomass as a fuel, the fuel cell system is an extremely attractive option for many industrial users.

This year, as in those of the past, the Administration has recommended dramatic reductions in this program. The amounts required to bring this technology to within industry's financial conditions amounts to a small fraction of the cost of one new jet aircraft engine. Yet, the most revolutionary of the new power generation technologies yet conceived by our best technical brains appear very low on the list of the Administration's budget priorities. Society is in debt to the Congress, and this Committee in particular, for the courage to continue including funds directed toward the advancement of fuel cells in the Annual Appropriation Bills.

Although industrial interest is primarily in advanced systems such as molten carbonate and solid oxide electrolyte, our Association has a concern that unless the phosphoric acid program is brought to early commercialization, demonstrating that fuel cells are "for real", support for the entire fuel cell program will start to slip badly. There will be nothing quite so beneficial to the fuel cell program as having an operating fuel cell plant, of any type.

available for inspection by the industrial decision makers. Once these individuals perceive that fuel cells are a viable option for their industry or business, they will vote with their checkbooks to make the fuel cell industry take off with a high rate of applications in all industries. For this reason, we of the Industrial Fuel Cell Association recommend that FY 1987 support be continued at the FY 1986 levels for all fuel cell programs.

Mr. Chairman, I thank you and the Subcommittee for your sustained interest in this attractive energy conversion technology and request your continued support. I will be happy to respond to any questions or comments on these remarks.

February 24, 1986

Senator EVANS. Thank you, very much. Mr. Light, from an electric utility viewpoint, what do you see ahead as the potential of this technology versus some of the more typical alternative technologies in the development of new electrical energy? I am speaking of some continued technological improvements in light-water reactors, and other sources, as well.

Mr. LIGHT. Senator, I think for the electric utilities that are particularly in the densely populated urban areas, that the fuel cell technology offers rewards in the very near-term future. The utilities are faced with the predicament at this time, where it is difficult to find boards of directors that will authorize an investment in continued nuclear—I don't think that you would find any board in its right mind under the present-day standards that would authorize an investment in a $4 billion plant that takes 12 years down the road to utilize.

Unfortunately, coal is rapidly approaching that. The large fossil-fired plants will cost, with the present environmental controls, close to $1 billion plus, and they take 4 to 5 years to build.

For the foreseeable near-term future, and I mean up to possibly the year 2000, I would expect that we would need this type of interim production capabilities, particularly in areas where there is urban cities, where they would fit very well. And I would think that the commercial application to Public Service Electric & Gas, Con Edison, Pacific Gas & Electric, and companies such as that, would be real in the near-term future.

Senator EVANS. Looking a little past the near-term future, I know it gets much more iffy, but if we were to proceed ahead and the end result of current research were to get these plants down to a reasonable level, what share of electric power production 15 to 20 years from now might this provide?

Mr. LIGHT. That would be difficult to estimate.

Let me give you an estimate of what our production in the Public Service System is at this time. We generate presently approximately 50 percent coal; of that 25 percent is imported from the western Pennsylvania and Ohio Valley area. We are 25 percent nuclear, and the other 25 percent is basically natural gas, oil, and jet engines, topping peaking units.

I would think that the area where fuel cells would make their penetration would be in that 25 percent. So I would not expect that it would exceed 15 to 20 percent in the future, but in the period from now until the late 1990's, I would expect that it could have a significant contribution.

Senator EVANS. Mr. Jones, what about your anticipation? You specifically talked about the chlor-alkali industry, which is an important one up our way. Would you say that it has the potential—the aluminum industry is another one where there is a very large amount of electrical use. How far away are you from this having any particular benefit in industrial processes like that?

Mr. JONES. Well, one of the not too well-known statistics is that 14 percent of all of the electricity that is consumed in the United States is consumed as direct current, which the fuel cells produce, and of the chlor-alkali industry and the aluminum industry, when they were running their reduction plants were the primary users of this electricity.

I got interested in fuel cells when I worked for Reynolds Aluminum, and could see the broad application of a direct current generator to a electric chemical process. If the economy were going to come back so that we began to produce primary metals and things again like that, I could see perhaps double the growth that we have talked about here, within in-plant generation for these industries—especially the chlor-alkali industry where the cell gives off hydrogen gas and by recycling the hydrogen gas back to the fuel cell, you can make a 19–20-percent improvement just in the basic efficiency of the process.

The aluminum business is a little bit different, but it is hard to answer unless you know what is going to happen to our industrial base within the next period of time, but this does represent one of the tools which, if it were in place, could help us strengthen our industrial base in primary metals.

Senator EVANS. Is there any other currently noncommercial, power-generation source that, in your view, offers as much potential for commercialization over the next 15 years?

Mr. LIGHT. That is an interesting question for you to ask. I worked for 22 years as a researcher on MHD, and I think fuel cells has it hands down over MHD. Most of my work presently is with fluidized bed combustion of coal and with combustion turbine installations. I can see the fuel cell, in some circumstances, fitting a niche in the cogeneration industry, at the small power end of the cogeneration business.

The combustion turbines, as they get larger in size, improve in efficiency, and the small-sized turbines are not very efficient and so they can't compete very well. So, in the range of up to 200 kilowatts, up to say 2 or 4 megawatts, the fuel cell has a constant efficiency, after it once gets so big, its efficiency is constant. So I can see a big market in the cogeneration area for fuel cells in the small sized plant, but that is where most of the plant sizes will be in the future.

Senator EVANS. Senator Matsunaga.

Senator MATSUNAGA. Thank you, Mr. Chairman. I have no questions, but I would like to thank you, Mr. Light, for sharing your brightness on the subject, and thank you, Mr. Jones, for traversing the continent to share your views with us.

Thank you, very much.

Senator EVANS. Thank you, both.

Now, we will take panel No. 3. We are running into headwinds as far as other things are concerned. We will take panel 3 and ask that you summarize your statements and then it will be necessary to recess until about 1:45 for panels 4 and 5, and I hope that that will still allow those that are participants to come back because this is an important area. I would like to listen to the testimony and I don't know whether Senator Matsunaga will be able to return or not, but all of this will be on the record and be part of our consideration.

Senator MATSUNAGA. Mr. Chairman, I have a commitment for which I am already delayed, but before I go, I wish to thank Mr. Glenn and Dr. Mechlin for their testimony. I have your written statements and I will read them carefully—as a matter of fact, I

have already ready some of your testimony. I apologize to the other panel members that I will not be able to be present.

But thank you all for coming to share your views with us. Thank you.

Senator EVANS. We have on panel No. 3, Don Glenn, vice president, Energy Research Corp., and Dr. George Mechlin, vice president of research and development, Westinghouse Electric Corp. Representatives of IFC were invited and unfortunately could not attend today, but we expect and hope to get information from them so we have the manufacturers represented—the three that are currently active in the United States.

Let's start with Mr. Glenn.

STATEMENT OF DONALD R. GLENN, VICE PRESIDENT, ENERGY RESEARCH CORP.

Mr. GLENN. Thank you, Mr. Chairman. I am Donald R. Glenn, vice president of Energy Research Corp., ERC, a subsidiary of St. Joe Minerals Corp., a Fluor Co. I am very pleased to have been asked to provide testimony to your subcommittee as you deliberate on several bills to recognize and encourage the use of fuel cells fueled by alternative energy resources.

Before getting into the heart of my testimony, I have to preface my remarks with a caution. It takes much longer to bring supply-side energy and new power resources to the marketplace, and this does not consider foreign oil or gas sources and their unreliability. In setting your priorities in this fiscal climate, I hope that the other defense sensitivity, our energy security, is viewed as the equivalent in our power and industrial bloodline as weaponry is to our military.

ERC was founded in 1969 to specialize in developing new alkaline batteries and fuel cells. The company is among the top two U.S. firms dedicated to developing power products derived from electrochemistry. We are a U.S. leader in developing phosphoric acid and molten carbonate fuel cell systems, as well as several new battery technologies.

I applaud the Energy R&D Subcommittee for calling this hearing to explore the most efficient power generator technology currently known. I would also like to make the comment that I commend the staff for recognizing and organizing such a fine panel of people to represent us.

The two fuel cell technologies of greatest interest are the first generation phosphoric acid, and the next generation molten carbonate fuel cells. They differ in that the phosphoric acid operates at 375–425 degrees and generates power at about 40-percent efficiency, with another 40-percent equivalent available as cogenerated thermal energy.

Molten carbonate systems operate at 1,200 degrees and are able to achieve in excess of 60-percent electric efficiency, the highest ever demonstrated by any generation scheme, with an additional potential of upwards of 30-percent equivalent as high grade, clean, waste heat.

Both technologies use gaseous hydrocarbon fuels as the basic energy input. Candidate fuels include coal-gas, natural gas, methanol, ethanol, biomass-derived gas and, of course, hydrogen.

With no moving parts, the system is very efficient and does not suffer from efficiency losses associated with friction and rotating machinery. Fuel cell maintains this high efficiency operating from both partload through fullload situations.

With this as a start, I will begin to describe the phosphoric acid and molten carbonate technologies as they are being developed at ERC.

Among competing phosphoric acid systems, there is one basic difference and that relates to the way in which the excess heat produced in the fuel cell stack is removed. The heat removal, or cooling, is accomplished by either liquid, as a water compound, or gas, usually as air. ERC has chosen air cooling early in our research program for several reasons. The major advantage is the simplicity and reliability implicit with air cooling.

A second very significant advantage is that air is a good electric insulator compared with water, thereby eliminating high voltage electrical shorting problems. And, the air-cooled system requires fewer components.

ERC's air-cooled technology is the basis of a license and technology cooperation agreement with Westinghouse, as they develop their pressurized version of phosphoric acid fuel cells for utility applications.

The remainder of our work is directed into small capacity systems, stand alone, for residential, commercial, industrial, and mobility situations. In this area, we have been the U.S. Army's developer for a new generation of field generators in the 3–5-kilowatt-size range as an alternative to inefficient, noisy, and unreliable internal combustion engine-generator sets. We delivered two prototype units to the Army in the 1984–85 timeframe.

In support of the DOE Electric Vehicle and Energy Storage Programs, we designed and delivered a 30-kilowatt reformer and stack to Los Alamos National Laboratory for their use in gaining experience with fuel cell operation as may be directed toward transportation applications.

In 1985, ERC designed, built, and is now testing a neat-methanol unit for the Air Force, rated at 5 kilowatts. In this system, the water is produced internal to the unit and is recovered, thus the fuel cell can be fueled with pure methanol. This, coupled to a more advanced microprocessor-controller, marks the smaller capacity fuel cell state of the art.

We believe the trump card for power generation is molten carbonate fuel cells. For this more advanced technology there are also two major technical approaches. Instead of the cooling option, as exists in the phosphoric acid technology, two molten carbonate alternatives involve the manner by which incoming gas fuels are chemically converted to fuel cell compatible feeds.

We have perfected a technique called internal reforming where the chemical transformation is done within the fuel cell stack's anode compartment. We call this direct fuel cell.

This is a major breakthrough on the road to commercialization. By eliminating an external reformer, some associated heat ex-

changers and piping, our hardware costs are expected to be reduced, the system quite simple and a bonus of 10 to 20 energy efficiency points realized for a total of 60-percent electric efficiency because of the thermal-chemical benefit derived by integrating the reformer function to within the stack.

The direct fuel cell will accept any, or a combination of, methane-containing gas fuels indiscriminately. Should a biogas be a primary fuel and a reduction or biological upset curtail the gas supply, other available fuel gasses can be immediately switched into the feed lines to maintain power availability.

These units are rugged, easily transported and assembled into an operating plant. An EPRI study found that a 2-megawatt direct fuel cell dispersed generation plant design can be transported by four standard flat-bed trailers and, once onsite, only require attachment to mounting pads and interconnection of electrical and piping runs. The plant's footprint occupies under a one-eighth acre, including all maintenance accesses to each of the major pieces of equipment.

In 1985, ERC ran the first successful 1-kilowatt internal reformed stack. We now believe that improved ERC system designs may allow power generation at an unprecedented 70-percent electric efficiency, using methane gas fuels, and over 50-percent efficiency with a coal-derived gas.

Most remaining R&D associated with stack component scale-up, short stack assembly, and test, and, last, full-scale stack verification can be completed in about 2 years, or by the late 1988 timeframe. At that time, we will locate and test a stand-alone unit at between a 50–100-kilowatt capacity as a preproduction prototype.

We first presented this program plan to DOE and Congress 2 years ago, and believe it remains sound. The American preeminence in providing power generation hardware and powerplants is in serious jeopardy with respect to the molten carbonate concept. To be penny wise and dollar foolish at this juncture for this technology would effectively sever the creation of the best power producer ever conceived and surely give our markets in this area to others.

A few comments now about the alternative energy connection with fuel cells. By coupling high efficiency fuel cells with lower cost biomass fuels, economic benefits are available in much shorter timeframes than with other power generating system options. For example, a proposed application of phosphoric acid technology with a digester-produced methane gas resulted in a fourfold improvement in payback over the nearest next option with an equivalent energy savings, in oil equivalents, of almost 50 percent. Numerous other studies have evaluated other biomass and coal-derived fuels for use with fuel cells including landfill gas, grain alcohols, as ethanol and reformed methanol.

A significant cost feature of producing biomass alcohol fuels is concentration, or proof. Fuel cells can accept lower proof ethanol with up to 40-percent water content. As the costs to produce grain alcohol fuels vary with feedstock and the desired purity, no single value is representative of the fuel costs. However, an average of between $1.50 to $2 a gallon would be reasonable.

Fortunately, the high proof is not required for transportation missions. To achieve a 200–250-mile distance, only 60- to 65-percent purity levels are required, where fuel costs would average approximately 4 cents a mile.

Applications of fuel cells using biomass and other methane-or-hydrogen-producing feedstocks can produce quite, nonpolluting, reliable, and low-cost power to remote and rural locations, underdeveloped countries where few or no transmission and distribution systems are in place, and for many types of land and marine transportation schemes.

Further, cogeneration applications should be evaluated. For the digester application in the wastewater treatment plants I have just talked to, the baseline phosphoric acid system not only supplied all the baseload power, but also provided clean heat, as carbon dioxide and steam for thermal conditioning of the digesters to maximize gas production rates and to heat or cool the plant's buildings.

Similar synergism is available for alcohol fuel production processing itself.

In the interest of time, I will terminate my testimony. I thank you very much for the opportunity to present the status of our programs as connected with the alternative energy resources. Your committee has been most positive in supporting this technology and I promise you that these new power generators would justify your expectation and ours in just a very few more years.

[The prepared statement of Mr. Glenn follows:]

Statement of Donald R. Glenn

Vice President

ENERGY RESEARCH CORPORATION

United States SENATE

Committee on Energy & Natural Resources

Subcommittee on Research & Development

Pete V. Domenici, Chairman

Hearings on

FUEL CELL TECHNOLOGY

(and related legislation)

February 24, 1986

Statement of Donald R. Glenn

Vice President

I am Donald R. Glenn, Vice President of Energy Research Corporation (ERC), a subsidiary of St. Joe Minerals Corporation, a Fluor Company. I am very pleased to have been asked to provide testimony to your subcommittee as you deliberate on several Bills to recognize and encourage the use of fuel cells fueled by alternative energy resources. My statement presents a brief background of ERC, an overview of the two ERC fuel cell technologies - their operating fundamentals and current status, and finally, our position on several end use applications pertinent to the legislation proposed.

Before getting into the heart of my testimony, I have to preface my remarks with a caution. The civilian energy R & D program appears to be under attack by the Administration once again this year. In assessing the short term energy horizon, it may be convenient to create a case for dramatic, and disproportionate budget reductions (in energy development) from among the R & D agencies. However, there is no doubt that our energy wants, and the supply systems ability to respond to those demands have different time constants. It takes much longer to bring the supply-side energy and new power resources to the marketplace and this does not consider any foreign oil or gas sources and their reliability. In setting your priorities in this fiscal climate, I hope that the other "defense" sensitivity, our energy security, is viewed as the equivalent in our power and industrial

"bloodline" as weaponry is to our military.

About ERC

ERC was founded in 1969 to specialize in developing new alkaline batteries and fuel cells. Since those beginnings, the company has shown steady growth to where today it is among the top two U.S. firms dedicated to developing power products derived from electrochemistry. Our staff is now 165 strong with about 1/3 having technical degrees and professional experience in electrochemical sciences and engineering. The company is located in Danbury, Connecticut. ERC is a U.S. leader in developing phosphoric acid-and molten carbonate-fuel cell systems as well as silver-zinc, nickel-cadmium and zinc-bromine batteries for a variety of applications and customers.

About Fuel Cells

I applaud the Energy R & D Subcommittee of the Committee on Energy and National Resources for calling this hearing to explore the most efficient power generator technology currently known.

The two fuel cell technologies of greatest interest to ERC and the electric power industry, are the first generation phosphoric acid (PAFC) and the next generation molten carbonate (MCFC). They differ in that the PAFC operates at 375-425 degrees and generates power at about 40% efficiency with another 40% equivalent available as cogenerated thermal energy. MCFC systems

operate at 1200 degrees F and are able to achieve in excess of 60% electric efficiency, the highest ever demonstrated by any generation scheme, with an additional potential of 30% equivalent as high grade "clean" waste heat. Both technologies require gaseous hydrocarbon fuels as the basic energy input. The differing operating temperatures of the two fuel cell stacks imposes distinctive challenges in processing the incoming fuel gas to the hydrogen-rich input stream common to all fuel cells. Candidate fuel sources include coal-gas, natural gas, methanol, ethanol, biomass derived gas and of course, hydrogen.

The unique feature of a fuel cell is that it is an electrochemical conversion process. With no moving parts and only catalytically-stimulated reactions required at constant temperatures, the equipment is quiet, virtually non-polluting and very efficient as compared to other power producers. With no moving parts, frictional losses are not a factor. Fuel cell efficiency is associated with thermally-driven processes and chemical reactions. Unlike rotating machinery, the fuel cell maintains its high efficiency operating from part-load through full-load. With this introduction, I'll now describe ERC's Phosphoric Acid-(PAFC) and, most exciting, Direct Fuel cell (DFC) programs.

PAFC

Among the community of PAFC systems, there is one basic and very impactful difference and that relates to the method of removing

the excess heat produced in the fuel cell stack. The heat removal, or cooling, is accomplished by either liquid (as a water compound) or gas (as air). ERC chose air cooling early in our research program for several reasons. The major advantage is the simplicity and reliability implicit with air cooling. The sealing and distribution of air and gas fuels at ambient or low pressures is much easier, particularly when the two streams come into close proximity while within the very restricted channels of the fuel cell stack geometries. A second very significant advantage unique to the ERC scheme, is that air is a good electrical insulator compared with water, thereby eliminating high voltage electrical shorting problems. Also, the air-cooled system requires fewer components.

ERC's air-cooled technology is the basis of a license and technology cooperation agreement with Westinghouse Corp. as they develop their pressurized PAFC powerplant for utility applications. Under this agreement, ERC continues to improve on the air-cooled fuel cell technology and performs full-area short-stack life cycle testing for the Westinghouse project. The remainder of our PAFC work is directed towards smaller capacity, i.e. 2 to 40 kw, stand-alone systems for residential, commercial, industrial and mobility applications. In this area, we have been the U.S. Army's developer for a new generation of field generators in the 3-5 kW size as an alternative to inefficient, noisy and unreliable internal combustion engine-generator sets. ERC delivered two prototype units to the Army in 1984/1985. These are fueled by methanol and water (called premix methanol), are microprocessor controlled fully automatic units, and have met

most of the required goals of the program. In support of the DOE Electric Vehicle and Energy Storage Programs, ERC designed and delivered a 30 kW reformer and stack to Los Alamos for their use in gaining experience with fuel cell operation as may be directed towards transportation applications.

In 1985, ERC designed, built and is now testing a neat-methanol unit for the Air Force rated at 5 kW. In this system, the water produced internal to the unit is recovered and thus the fuel cell can be fueled with pure methanol. This, coupled to a more advanced microprocessor-controller marks the smaller capacity PAFC state-of-the-art. This design can be converted to use natural gas, naptha, or biomass derived methane/CO_2 gas fuels.

MCFC

ERC believes the "trump card" for power generation is the MCFC. For this more advanced technology there are also two major technical approaches. Instead of the cooling option as in PAFC, the two MCFC design alternatives involve the fuel processing function or the manner by which the incoming gas fuel is chemically converted to fuel cell compatible feeds. The more conventional method is to have a separate device (a reformer) and associated plumbing to take the hydrocarbon gas and react it to a hydrogen and carbon monoxide form. ERC has perfected a technique called internal-reforming where the same chemical transformation is done within the fuel cell stack's anode compartment. We call this the Direct Fuel Cell (DFC). This is a major breakthrough on

the road to commercialization. By eliminating an external reformer, some associated heat exchangers and interconnecting piping, the hardware costs are reduced, the system simplified and there's a bonus of 10-20 energy efficiency points for a total of 60% electric efficiency because of a thermochemical benefit derived by combining the reformer and anodic reactions to within a single compartment. In very simple terms, the reforming reactions requires heat (endothermic) while the fuel cell emits heat (exothermic). Thus one reaction satisfies the thermal requirements of the other. Further, steam is a by-product of the anode reaction and is used by the reforming function another (chemical) synergism.

The Direct Fuel Cell will accept any, or a combination of, methane-containing gas fuels indiscriminately. Should a biogas be the primary fuel and a reduction or biological upset curtail the gas supply, other available fuel gas can be immediately switched into the feed lines to maintain power availability. The only major prerequisite is that a gas cleanup function precede the fuel cell stack to remove sulfur and other impurities. Constructed mainly of alloyed stainless steels, MCFC materials of construction are relatively inexpensive. Although reasonably corrosion resistant, the cells are still vulnerable to degradation due to the high operating temperature's adverse effects on material properties. These units are rugged and easily transported and assembled into an operating plants. An EPRI study found that a 2 MW DFC dispersed generation plant design can be transported by four standard flat bed trailers and,

once on site, only require attachment to mounting pads and interconnection of electrical and piping runs. The plant's footprint occupies 1/3 acre including maintenance access to each pallet.

In 1985, private funded tasks resulted in the first successful demonstration of a 1kW internal reforming stack. Also in 1985, privately-funded studies indicated that improved ERC system designs may allow power generation at an unprecedented 70% electric efficiency using methane gas fuels and over 50% with coal derived gas. The coal-electric option would also be pollution free in this embodiment.

I will now address where we are in this fascinating advance. ERC believes that most remaining R & D associated with stack component scale-up, short stack assembly and test, and lastly, full-scale stack verification can be completed in about two years, or by the late 1988 timeframe. At that time, ERC will locate and test a stand-alone unit at 50-100 kW, as a preproduction prototype. To get there, and in my view it isn't soon enough, ERC needs a sustained DOE commitment of $5.0 million in FY 1987 and $2.5 million in FY 1988. This will be augmented by $2.5 million already promised from the private sector. The FY 1987 DOE Budget Request has (once again) short-changed the MCFC and DFC activity.

Presently, there are only two U.S. manufacturing firms in the advanced stages of MCFC technology development with ERC being the only wholly U.S.-owned company. Japan, our major foreign

competitor, has seven companies active in MCFC R & D and fully aware of the lucrative markets ahead. They are planning a multiyear, $250 million program to bring MCFC to commercial maturity. Italy and Holland are also planning multi-million dollar programs. The argument of whether internal or external (conventional) reforming is the best method is a moot point knowing the impact this advanced fuel cell technology will have on our domestic use of fuels to meet the steadily rising demand for electricity. Both efforts should receive adequate funds. As I said, we see our DFC approaching a state where a field test of a first building block module continues to remain firm (in late 1988/early 1989), evidence that the ERC work is moving as planned with no new technical "stoppers" noted. We first presented this program plan to DOE and Congress two years ago and believe it remains sound. In recent years, the Congress has been concerned that U.S firms performing fuel cell R & D guard this technology for American markets because of the growing competitive programs overseas, the American preeminence in providing power generation hardware and powerplants is in serious jeopardy with respect to the MCFC concept. To be penny-wise and dollar foolish at this juncture for this technology would effectively sever the creation of the best power producer ever conceived and surely give our markets in this area to others.

Alternative Energy Sources and Fuel Cells

By coupling high efficiency fuel cells with lower cost biomass-derived fuels, economic benefits are available in much

shorter timeframes than with other power generating system options. For example, a proposed application of PAFC with digester-produced methane gas resulted in fourfold improvement in payback over-the nearest-next option with an equivalent energy savings, in oil equivalents, of almost 50%. Numerous other studies have evaluated other biomass - and coal-derived fuels for use with fuel cells including landfill gas, grain alcohols (as ethanol and reformed methanol).

A significant cost feature of producing biomass (grain) alcohol fuels is concentration, or proof. Fuel cells can accept lower proof (low purity) ethanol with up to 40% water content. As the costs to produce grain alcohol fuels vary with feedstock (corn, wheat, rye, sugar cane, etc.) and the desired purity, no single value is representative of the fuel costs. However, if I assume that 190-proof, or pure alcohol is the end product, the per gallon costs vary from approximately $1.50 to $2.00. But, fortunately, this high proof is not required in transportation missions. To achieve 200-250 mile distances, only 60-65% purity levels are needed with fuel costs at about 4 cents/mile, longer distances would require higher purity blends.

Applications of fuel cells using biomass and other methane-or hydrogen-producing feedstocks can bring quiet, non-polluting, reliable and low cost power to remote and rural locations, underdeveloped countries where little or no transmission and distribution systems are in place, and for many types of land and marine transportation. Further, cogeneration applications should

be seriously evaluated. For the digester application in wastewater treatment plants, the baseline PAFC system not only supplied all the baseload power but also provided "clean" heat, as CO_2 and steam for thermal conditi ning of the digesters to maximize gas production rates and to heat or cool the plant's buildings. Similar synergism is available for alcohol fuel production process itself. The manufacture of grain alcohol includes several lower temperature steps such as cooking, fermentation, distillation and evaporation. Because fuel cells are modular, fuel production can be sited on farms, at grain or other crop surplus storage locations as well as within utility powerplants. Safety issues must be addressed, particularly if higher purity alcohol fuel is mandated. However, low-proof (60%) ethanol, for example, is safer to handle and it is well-below toxicity levels for gasoline blends.

Thank you for allowing me this opportunity to present ERC's fuel cell programs status and fuel cell opportunities with alternative energy sources. Your committee has been most positive in supporting this technology. I promise you that these new power generators will justify your expectations, and ours, in just a very few more years.

Senator EVANS. Thank you for a fascinating expression.
Dr. Mechlin.

STATEMENT OF DR. GEORGE F. MECHLIN, VICE PRESIDENT, RESEARCH AND DEVELOPMENT, WESTINGHOUSE ELECTRIC CORP.

Dr. MECHLIN. Good afternoon, Mr. Chairman, ladies and gentlemen. My name is George Mechlin. I am vice president for research and development of the Westinghouse Electric Corp. It is a great privilege to be allowed to speak before you today. In the interest of conserving your time, I will abbreviate my remarks over my written testimony.

I am here to speak on behalf of continued national support of research and development on fuel cells, as a much needed and very promising element of our future means of generating electricity from fossil and renewable fuels in a safe, efficient, and environmentally benign fashion.

I need not apprise this committee of the promise, virtues, or benefits of fuel cells. I know you have heard this story many times, but there is a need for continued national support for fuel cell development. That need arises from the fact that while the basic technology is well understood, there are important technical refinements in materials and designs yet to be achieved.

Testing necessary to achieve the accepted status of a proven technology requires substantial future research and development.

Two elements of risk can be identified in energy projects. The first risk is the ability of the technology to perform the hoped-for function. The second is the acceptance of the public at large that the new capability is needed and produces benefits sufficient to justify market prices which must be paid. The supersonic transport aircraft is an excellent example. No one can doubt that the SST can fly at supersonic speed. It seems equally certain that for the great majority of travelers, the time saved is worth much less than the premium costs. The market is obviously much, much smaller than the project sponsors had hoped for.

The business community has come to regard energy research as a very risky and unpredictable undertaking. There are continuing wide swings in prices and availabilities occurring over timespans comparable to the incubation times of the technological projects which produce new energy sources or more efficient devices.

One need look only at what is said by some to be a dangerous overextension of credit by our banking institutions to certain oil-producing, developing countries, to obtain a measure of the deep concern of the money managers of the United States toward investment in energy projects.

The research and development efforts on the several types of fuel cells have progressed to the point where an evolution of technologies can confidently be predicted in much the same manner as the evolution of aviation, which produced successively higher performance capabilities and larger aircraft as aluminum replaced varnished canvas and turbojets replaced piston engines. Fuel cells, based on phosphoric acid as an electrolyte, represent a near-at-

hand generation of technology with impressive advantages in efficiency and environmental quality.

A later generation just emerging from the research phase based on the electrical conducting properties of certain meal oxides at elevated temperatures offers increased efficiency, fuel versatility, and application flexibility in the future.

The research and development efforts on both of these fuel cell systems are currently being supported by substantial funding from the private sector and by the Department of Energy and are threatened with extinction by shortsighted budget cutting motives of the executive branch.

To expect that the private sector will alone accept the general risks inherent in energy projects is unrealistic. A more accurate view is the withdrawal of Government research and development support will be interpreted by the private sector as a clear signal that the risk has risen to an unacceptable level and the private sector will withdraw also, leaving only the collapse of future hopes for the technology and its contribution to our society.

The case for continued national support of fuel cell research and development is very strong. It is based on a series of important considerations. In the early years of the next decade, there is a growing concensus that the electric utility companies in some regions of our country will be unable to install or obtain sufficient generation capacity to meet the needs of our homes and factories.

This shortage will not be easy to rectify by conventional generation technology, meeting all the restraints imposed by the need to preserve the optimum use of land and water resources which would be required for generation sites, for transmission lines, and waste disposal.

The preservation of air quality values and the amelioration of acid rain impose further burdens which conventional electricity generation technology finds increasingly difficult to meet. The finance and time constraints which exist on powerplant and transmission line construction are further obstacles to the timely amelioration of what will be a growing capacity shortage. That this shortage of electricity will exacerbate the disadvantages in industrial competitiveness which is already a domestic employment problem and a major international trade problem for our country is a very alarming prospect.

The compactness and environmental compatibility of the fuel cell makes it a very desirable option to have available to be put into utility systems where it is needed with short lead times and with excellent fuel efficiencies which lead to electricity costs acceptable to consumers.

The solid oxide version of the fuel cell is additionally very suitable for cogeneration because of the high quality of the reject heat so as to be a potential significant additional improvement to our industrial competitiveness.

I am pleased to report that the national research support of past years has made the United States the undisputed leader in fuel cell technology. The advantages in efficiency, in environmental quality, in flexibility of siting and short installation lead times make fuel cell electricity generating systems as attractive in all countries as they are in the United States.

Japan is a particularly interested country. The Ministry of International Trade and Industry and the Agency of Industrial Science and Technology are systematically funding and encouraging Japanese industry to duplicate and acquire fuel cell technology equivalent to that where we now have technological superiority. If we maintain our lead through continuation of our national support of research and development which I would judge to be about 5 years, we can maintain the Japanese, and all other countries as well, as customers for our equipment.

That this is possible is evidenced by the U.S. aviation industry. Fuel cells for the generation of electricity are an opportunity for jobs and prosperity in the United States which the wise programs of the past have put in our hands. We need your support and action in continuing the research and development efforts which will bring this much needed technology to fruition as an element of our mix of electricity generation options and an advantage in international trade.

Our people will work with you and your staff on the details of our fiscal 1987 funding needs. We will provide you whatever data might be needed for you to make your appropriation determinations for 1987.

If Senate Bills 1686 and 19687 can contribute to this end, and they appear to do so, then they should be considered. The important thing is that adequate support by continued.

My company appreciates the role that Congress has played in providing some of the crucial resources necessary to move these promising technologies toward commercialization. Thank you, and I am prepared to answer any questions.

[The prepared statement of Dr. Mechlin follows:]

FUEL CELL TECHNOLOGY DEVELOPMENT

Testimony by

Dr. George F. Mechlin
Vice President - Research and Development
Westinghouse Electric Corporation

24 February 1986

Before the

Subcommittee on Energy Research and Development

of the

Committee on Energy and Natural Resources

United States Senate

Good Morning Mr. Chairman, Ladies and Gentlemen:

My name is George Mechlin. I am Vice President for Research and Development of the Westinghouse Electric Corporation. It is a great privilege to be allowed to speak before you today.

Those of us who work for Westinghouse are the heirs of a hundred years of energy research and development. We are a company which maintains a close touch world-wide with electric utilities, equipment manufacturers and the consumers of electricity.

Our founder, George Westinghouse, introduced alternating current as the now standard and universal basis for electricity utilization. In this tradition, Westinghouse is participating in a broad spectrum of the national energy development efforts. This includes advanced combustion turbines (heat engines), surface coal gasification and gas cleanup, and magnetohydrodynamics (MHD). We are involved in a number of conservation efforts such as atmospheric fluidized bed air heaters, combustion systems studies for advanced pressurized fluidized bed combined cycle systems, and photovoltaics and wind turbines.

I am here to speak on behalf of continued national support of research and development on fuel cells as a much needed and very promising element of our future means of generating electricity from fossil fuels in a safe, efficient and environmentally benign fashion.

To briefly refresh your memories, fuel cells are a kind of electric battery which derive their energy not from the chemical reactions of the structures within the batteries as those of our flashlights or automobiles, but from fuels fed externally. This means that electric energy will be generated continuously as long as fuel is fed to the cell. Fuel cells thus have no moving parts to wear and the principles which underlie the energy conversion allow efficiencies substantially higher than even the best of our conventional rotating machine sources. Further, the nature of the chemical processes in the fuel cell are such that no environmentally degrading by-products are produced such as nitrogen oxides - one of the progenitors of acid rain.

The need for continued national support arises from the fact that while the basic technology is well understood, there are important technical refinements in materials and designs yet to be achieved. Testing is necessary to achieve the accepted status of a proven technology require substantial future research and development.

Two elements of risk can be identified in energy projects. The first risk is the ability of the technology to perform the hoped for function. The second is the acceptance of the public at large that the new capability is needed and produces benefits sufficient to justify market prices which must be paid. The supersonic transport aircraft is an excellent example. No one can doubt that the SST can fly at supersonic speed. It seems

equally certain that for the great majority of travelers, the time saved is worth much less than the premium costs. The market is obviously much, much smaller than the project sponsors had hoped for.

The business community has come to regard energy research as a very risky and unpredictable undertaking. There are continuing wide swings in prices and availabilities occurring over time spans comparable to the incubation times of the technological projects which produce new energy sources or more efficient devices. One need look only at what is said by some to be a dangerous over-extension of credit by our banking institutions to certain oil producing, developing countries to obtain a measure of the deep concern of the money managers of the United States toward investment in energy projects.

The research and development efforts on the several types of fuel cells have progressed to the point where an evolution of technologies can be confidently predicted in much the manner as the evolution of aviation which produced successively higher performance capabilities and larger aircraft as aluminum replaced varnished canvas and turbo-jets replaced piston engines. Fuel cells based on phosphoric acid as an electrolyte represent a near-at-hand generation of technology with impressive advantages in efficiency and environmental quality. A later generation just

emerging from the research phase based on the electrical conducting properties of certain metal oxides at elevated temperatures offers increased efficiency, fuel versatility and application flexibility in the future.

The research and development efforts on both of these fuel cell systems are currently being supported by substantial funding from the private sector and by the Department of Energy and are threatened with extinction by short sighted budget cutting motives of the executive branch. To expect that the private sector will alone accept the general risks inherent in energy projects is unrealistic. A more accurate view is that the withdrawal of government research and development support will be interpreted by the private sector as a clear signal that the risk has risen to an unacceptable level and the private sector will withdraw also leaving only the collapse of future hopes for the technology and its contribution to our society.

The case for continued national support of fuel cell research and development is very strong. It is based on a series of important considerations. In the early years of the next decade, there is a growing consensus that the electric utility companies in some regions of our country will be unable to install or obtain sufficient generation capacity to meet the needs of our homes and factories. This shortage will not be easy to rectify by conventional generation technology, meeting all the restraints imposed by the need to preserve the optimum use of land and water

resources which would be required for generation sites, for transmission lines and waste disposal. The preservation of air quality values and the amelioration of acid rain impose further burdens which conventional electricity generation technology finds increasingly difficult to meet. The finance and time constraints which exist on power plant and transmission line construction are further obstacles to the timely amelioration of what will be a growing capacity shortage. That this shortage of electricity will exacerbate the disadvantages in industrial competitiveness which is already a domestic employment problem and a major international trade problem for our country is a very alarming prospect. The compactness and environmental compatibility of the fuel cell makes it a very desirable option to have available to be put into utility systems where it is needed with short lead times and with excellent fuel efficiencies which lead to electricity costs acceptable to consumers. The solid oxide version of the fuel cell is additionally very suitable for cogeneration because of the high quality of its reject heat so as to be a potential significant additional improvement to our industrial competitiveness.

I am pleased to report that the national research support of past years has made the United States the undisputed leader in fuel cell technology. The advantages in efficiency, in environmental quality, in flexibility of siting and short installation lead times make fuel cell electricity generating systems as attractive

in all countries as they are in the United States. Japan is a particularly interested country. The Ministry of International Trade and Industry and the Agency of Industrial Science and Technology are systematically funding and encouraging Japanese industry to duplicate and acquire fuel cell technology equivalent to that where we now have technological superiority. If we maintain our lead through continuation of our national support of research and development which I would judge to be about five years, we can maintain the Japanese (and all other countries as well) as customers for our equipment. That this is possible is evidenced by the United States aviation industry. Fuel cells for the generation of electricity are an opportunity for jobs and prosperity in the United States which the wise programs of the past have put in our hands. We need your support and action in continuing the research and development efforts which will bring this much needed technology to fruition as an element of our mix of electricity generation options and an advantage in international trade.

If Senate bills S-1686 and S-1687 can contribute to this end, and they appear to do so, then they should be considered. The important thing is that adequate support be continued.

Senator EVANS. Thank you, very much. Let me first ask each of you, what is the budget in each of your companies for fuel cells, what would be considered fuel cell research or investment during the course of the next few years?

Mr. GLENN. In the 3-year program that we initially provided with DOE, we have a $3 million promise from private sector interest, including our own corporation, as part of the total package, which was at that time costed out to be $15.5 million. That figure has grown some because of the slight decreases in the requested funding from the Government quarter, but in any case, the next year request from our company to the molten carbonate program would be on the order of $5 million, with $2.5 million over the next 2 years being provided by our company, plus some outside supporting, including EPRI and a utility.

Senator EVANS. How about Westinghouse?

Dr. MECHLIN. In the case of the phosphoric acid for fiscal 1987, the previously contemplated financial support would have been about $10 million with an equivalent sum being derived from the private sector partly as cost-sharing in the formal sense of the contract, and partly as capital investments in production facilities and partly by customers in investments in equipment.

In the solid oxide, the situation is roughly equivalent except that sums are about half of this, with about $5 million previously expected in DOE contributions with cost sharing, capital investments, and investments by customers being on the order of $7.5 million.

So private sector has been putting in and is expected to put in about equivalent sums to what the Federal Government, and some cases, a little more.

Senator EVANS. Westinghouse has a long history in electric power equipment and production and research. How would you rank where we are now in fuel cell development with other kinds of research, other alternative, both expected and current electrical production?

Dr. MECHLIN. The thrust of much of the research and development of past years has been toward improved efficiency, therefore lower electricity costs by increasing the scale of powerplants. Not more than 20 years, a powerplant that generated perhaps 250 megawatts was considered quite large. Those unit sizes were pushed up, in the nuclear cases, to where they were over 1,000 megawatts. Those were very successful efforts in that they achieved the cost objectives, steadily falling price of electricity.

However, the end of that technological approach is at hand because the sociological factors of siting, environmental entrusion, and relative inflexibilities that those create in our social system point toward a much more environmentally and socially benign technological approach. In this environment, which I think we will see persist on into the indefinite future, the fuel cells represent a remarkably adaptable, efficient and prospectively cost-efficient way of generating electricity. Very promising.

Senator EVANS. Seems to me there is one that you didn't mention specifically and that is the uncertainty of load forecasts and load futures which we ran into in our own power planning in the Northwest, which is leading utilities to shy away from anything that has as long lead time as a major central plant. It seems to me

that that is another consideration, the unitizing ability of these producers and the short lead times for construction.

Is there anything else that has all of those attributes that comes close to the fuel cell as a competitor, potential future competitor?

Dr. MECHLIN. There is not at this time. It is unique in its flexibility, of siting, short lead time and environmental quality.

Senator EVANS. I appreciate that this is building from each panel into a pretty persuasive case. I only wish that the Department of Energy had stayed here and listened to the whole thing. Perhaps they do have representatives in the audience.

We now will be forced to recess and will resume at 2 p.m. If there are some, and I wish we could have gotten through the entire series of panels this morning—if there are some in panels 4 and 5 who, for any reason, cannot come back, we would be pleased to have your entire written testimony and would very likely want to submit written questions to you to elicit what otherwise could have come through the hearing. I hope the people will be able to return. We will resume at 2 p.m.

[Whereupon, at 12:45 p.m., the hearing was recessed, to reconvene at 2 p.m., the same day.]

AFTERNOON SESSION

Senator BINGAMAN [presiding]. Why don't we go ahead and get started here? Senator Evans will be here very shortly, I am told. But if we could go ahead and start the hearing back up with panel No. 4. Maybe each of the members of panel 4 could come forward here.

I guess the normal practice we have been following is for each witness to summarize their statement, and then we will have some questions. Perhaps we could start on my left, your right, and go right across. Go right ahead.

STATEMENT OF DR. SAIFUR RAHMAN, ASSOCIATE PROFESSOR, ELECTRICAL ENGINEERING DEPARTMENT, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Dr. RAHMAN. Thank you, Mr. Chairman and members of the subcommittee. Good afternoon. I am with Virginia Polytechnic Institute and State University. I teach in electrical engineering.

Today, I appreciate this opportunity to appear before this subcommittee to provide information about the renewable energy/fuel cell hybrid power generation. My testimony has already been submitted for the record. Now, I would like to summarize my comments.

Here, my remarks will be based on my own research work, discussions with other researchers in this field, and my technical visits to other countries.

I would like to address the issue of fuel cell powerplant and renewable energy hybrid systems. I believe this aspect of fuel cell application and the necessary R&D needs more attention than it has received. I would like to draw your attention to the potential operational support the fuel cell powerplant can provide. This may make wind and solar energy based electric power generation more valuable.

For this purpose, I shall look at both grid-connected and stand-alone applications. My remarks will be directed toward both the United States and overseas markets.

Please let me first talk about remote and stand-alone applications. I believe that we need to direct some of our research and development efforts toward studying the renewable and fuel cell cell hybrid energy systems. This would ensure optimum resource utilization at the minimum possible cost.

One area of emphasis can be the isolated and stand-alone photovoltaic and wind energy systems which compete with diesel generation. Some of the applications that may be studied are in East Asia and the Pacific. There are significant commercial applications of photovoltaic power in French Polynesia, Western Samoa, Fiji, and the Cook Islands.

By commercial application it is meant that these photovoltaic power generators are privately owned and are competing against other fuels, primarily diesel, without any subsidies. Possible use of fuel cells to supplement photovoltaic and windpower generation in these areas would, I believe, improve the living conditions of these local people and increase the market for fuel cells.

Now, about grid-connected applications. I would like to suggest that the possibility of using fuel cells to provide load-following support to renewable energy based power generation be examined a little more carefully. For large-scale integration of photovoltaic and windpower with electricity grid, there is a need for backup generation.

At present, in the integrated mode, the relatively vast size of electric power grid works as a backup. There are, however, certain problems with this approach. The intermittent nature of photovoltaic and wind-powered output may cause large fluctuations and control problems for the grid power.

Here I propose that the photovoltaic and wind-powered generation be supplemented with fuel cells which can provide the load-following requirements.

Now about some demonstration projects. Once the application of fuel cells to provide operational support for photovoltaic and windpower has been identified, one would think about pilot projects for demonstrating the proof of this concept. One might propose putting some small fuel cell powerplants in the field and let them run in parallel with some wind turbine generators or photovoltaic arrays. But I think more analysis and studies are needed to identify the response characteristics required from fuel cell powerplants and the related-cost benefit issues for such operation.

Therefore, I would like to propose that these studies and research activities precede more demonstration projects in the field of integrated operations.

Here, I would like to add that this a different approach from demonstration projects as compared to what is going on in the United States. In Japan, for example, the new energy development organization contracted with four different companies to independently develop 1 megawatt prototype fuel cells, such that they get a chance to give four different design groups to try out their ideas independently and see who comes out ahead. And if you know

what is going on in the United States, this contrasts with the approach followed in the United States so far.

Therefore, Mr. Chairman, in conclusion, I would like to say the following: The fuel cell technology is still in the developing stages. Protypes are being built for field testing. This is an opportune time for identifying the special characteristics needed in the fuel cell powerplant design for hybrid operation with renewable source of power.

I believe this would open up significant new markets for fuel cells. And, finally, I support the Senate bills S. 1686 and S. 1687 for this purpose. Thank you.

[The prepared statement of Dr. Rahman follows:]

TESTIMONY OF SAIFUR RAHMAN

ASSOCIATE PROFESSOR
ELECTRICAL ENGINEERING DEPARTMENT
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
BLACKSBURG, VA 24061

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
OF THE COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE
WASHINGTON, D.C.

February 24, 1986

Mr. Chairman and Members of the Subcommittee:

I appreciate the opportunity to appear before this subcommittee to provide information about the advantages of combining fuel cell power generation with renewable sources such as wind and solar. My comments will be based on discussions with other researchers, and technical visits to various countries. I believe this aspect of fuel cell application, and the necessary R&D, needs more attention than it has received. I would like to draw your attention to the potential operational support the fuel cell power plant can provide to solar and wind power plants. Such hybrid operation makes wind and solar energy based intermittent electric power generation more valuable because it smooths out the fluctuations. In my testimony I shall look at both grid-connected and stand-alone applications, and discuss the R&D needs to make the fuel cell a more valuable source of power. My remarks will be directed towards both the United States and the overseas markets.

The development of photovoltaics (PV) based electric energy systems for stand-alone applications has been extensively discussed in the technical literature [1-23]. The most common type of PV energy system design involves

battery backup. The battery is used to store the solar energy generated electricity and supply that energy back when there is no sunshine. More recently, however, there have been some discussions about diesel generator backup for large (several hundred kW range) PV arrays [16,23]. There are still other examples where wind and other intermittent sources of generation have been integrated with solar PV energy systems [24]. Also, there are demonstration projects where wind energy systems have been integrated with diesel engines for backup supplementary generation. One example is the Block Island wind-diesel project in Rhode Island [25,26].

Some researchers [19] have attempted to exploit the complementary nature of the wind and solar resource in order to provide a more stable supply and reduce the size of the battery backup necessary. The overall economic advantage of such hybrid systems (over the PV system alone) has not yet been proven. PV systems with battery backup remain the most common way to convert solar energy into electricity.

The diesel backup for PV systems is gaining some popularity now in remote locations as this makes a continuous 24-hour electric supply possible, at a capital cost lower than battery backup. One reason for this is the fact that, in many remote locations where PV is applied for electricity, diesel-electric generators already exist. The difficulty with diesel backup, however, is that these generators cannot always respond fast enough to the continually changing PV output. This is especially problematic when the size of PV capacity is more than 25% of system capacity. Moreover, when the diesel engine has to be run at low levels of output, because of high PV output, its efficiency decreases drastically.

In order to avoid these difficulties, I have proposed the integrated operation of the renewable energy generator and the fuel cell power plant [27].

This hybrid system eliminates the problem of slow response rate and low diesel engine efficiency at less than the rated output.

The inherent problem with any intermittent power source like wind and solar is that the system has to be oversized and a large backup storage is to be provided. This is because at the time of peak load enough wind or sunshine may not be available, thus one has to depend on the backup. Also in order to have adequate backup reserve for prolonged periods of no wind or sunshine, the system has to be oversized to provide enough charging power. If fuel cell power plants are made available to supplement renewable energy based generation, the need for oversizing the system and large backup capacity can be eliminated.

Remote and Stand-Alone Applications

I believe that we need to direct some of our research and development efforts towards studying the renewable and fuel cell integrated energy systems for optimum resource utilization at minimum cost. One area of emphasis can be the isolated and stand-alone photovoltaic and wind energy systems which compete with diesel generation. Some of the applications that may be studied are in East Asia and the Pacific. There are significant commercial applications of PV power in French Polynesia, Western Samoa, Fiji and the Cook Islands. These photovoltaic power generators are privately owned and are competing against other fuels, primarily diesel, without any government subsidies. However, due to the high cost of PV modules, and the need for redundancy and storage, these systems have generally been confined to lighting applications for well-to-do families. Possible use of fuel cells to supplement photovoltaic (and wind power) generation in these areas would improve the living conditions of the local people, and increase the market for fuel cells.

The combination of fuel cells and renewable energy sources can provide a two-fold benefit. First fossil fuel consumption would be reduced because:-(a) the fuel cell power plant is much more efficient than diesel engine and (b) the fuel cell power plant integrates more efficiently with renewable energy based power sources thus maximizing the output of these new power generation sources. The second benefit would be the reduction of power losses, since the fuel cell plant can be placed at or near the load center to take advantage of its low noise and emissions. Moreover, the fuel cell power plant can be designed to run on natural gas, methanol, biogas, coal gas, diesel fuel or any other hydrocarbon based fuel, and hydrogen, thus providing a wider choice of fuels for remote locations.

Grid-connected Applications

There are several examples of grid-connected applications of fuel cells in the United States and Japan. Pacific Gas and Electric Company has installed a 40-kW package of fuel cells to supply electricity and hot water to a large California state office building in San Francisco [28]. This plant uses natural gas as fuel. Southern California Edison is testing a 40-kW fuel cell power plant that runs on methane gas from a landfill at Industry Hills [29]. Tokyo Electric Power Company (TEPCO) and International Fuel Cell Corporation (IFC) are jointly evaluating a 4.5 MW fuel cell power plant in Tokyo [30]. This plant runs on natural gas and provides an overall AC efficiency of 36.7%.

I would like to suggest that additional research be conducted to investigate the possibility of using fuel cell power plants to provide operational support to renewable energy based power generation. Several studies [31-34] have looked into the effects of growing penetration levels, of renewable sources of generation, on the power system operation. Two major conclusions have emerged:

(i) Most approaches attempt to decrease the power output of the renewable source (e.g., solar, wind, etc.) in order to smooth out fluctuations; and

(ii) The renewable generation will be limited in its application unless new strategies to smooth out these fluctuations are devised.

Thus for large scale application of PV and wind power systems there is need for backup generation. At present, in the grid-connected mode, the relatively vast size of the grid works as the backup. There are, however, certain problems with this approach. The intermittent nature of PV and wind power output may cause large fluctuations and control problems for the grid power.

One strategy of integrating a large PV array into the electricity grid is to treat the photovoltaic power output as a negative load on the system load curve. Since, the array output variations are uncontrolled, the maximum probable increase or decrease in PV generation over a certain time will be large. Thus, a major effect of a PV array operated as negative load will be to increase the load following requirements. The same is true for large scale wind generation.

The fuel cell offers an attractive power generation option to meet these requirements. Ramping characteristics of the fuel cell power plant appear to match the array ramp rates. It can thus work as a load-following unit. So by adding fuel cell plants to the grid, the penetration level of PV and wind energy can be increased. The advantages of this arrangement are the following:

(i) Since the concept of negative load is used, the array output may be maximized without any modification of the utility's control system;

(ii) The load-following requirement will be met more efficiently; and

(iii) It will be possible to have large levels of PV and wind power penetration.

Demonstration Projects

One might propose putting some fuel cell power plants in the field and let them run in parallel with some wind turbine generators or photovoltaic arrays to study the benefits and problems of such hybrid operations. This will be similar to the approach taken for the Block Island (Rhode Island) wind-diesel experiment [25]. But there is a difference. Diesel engine is a mature technology while fuel cell is not. Fuel cells have been designed and prototypes used for space, military and electric utility applications. Several examples of utility application of fuel cell power plants have been given in the previous section. These were, however, designed to run as conventional utility generators. This mode of operation is very different from the fast reacting performance required to match the wind turbine generator or PV array output. More analysis and studies are needed to identify the response characterstics required from fuel cell power plants, and the related cost-benefit issues for such integrated operation. Therefore, I would propose that these studies and research activities precede more demonstration projects in this field of integrated opoeration.

Fuel cell technology is still under development. Prototypes are being built for field testing [35]. This is an opportune time for identifying the special requirements needed in the fuel cell power plant design for integrated operation with the renewable source of power.

I would like to add here that different countries approach demonstration projects differently. In Japan, for example, the New Energy Development Organization contracted with three companies to independently develop 1MW prototype fuel cell power plants. This gave three different groups of designers the opportunity to test their ideas. This will result in competing designs

which may give a better overall product. This contrasts with the approach followed in the United States thus far which was to use the design from one manufacturer and field test forty units.

Research and Development Needs

The objective will be to provide operational support to photovoltaic and wind power generators such that the hybrid system is totally capable of providing power which is sensitive to demand characteristics. In other words, the ramping characteristics of the fuel cell power plant must be fast enough to match the oscillations of wind or photovoltaic power output.

The 11MW prototype fuel cell power plant developed by United Technologies Corporation can operate between 30% and 100% of rated power [35]. Step changes in power within this operating range can be accomplished at approximately 1MW per second. The 1MW prototype fuel cell power plant being developed under the sponsorship of New Energy Development Organization in Japan can respond to a change in load from 250kW to 1000 kW in one minute [36]. The adequacy of these designs to match the oscillations of a wind turbine generator or a photovoltaic array, and at the same time to meet the varying power demand, must be investigated.

The fuel cell stack, because of the nature of the chemical reaction, is able to respond almost instantaneously to any load conditions within its range. The fuel reformer, on the other hand, has a much slower response rate. While there are no problems for steady state operation, the current design of reformers may not be able to produce the right amount of hydrogen enriched gas quickly enough to respond to fast changing loads. So far there has not been a strong need to address this issue. Because fuel cell power plants are generally

designed for steady state operation while connected with the electric utility power grid. But now we want to explore some different objectives.

Conclusion

In summary, I would like to suggest the following list of topics for further research.

i) Study how the dynamic load response rate of the fuel cell power plant can be improved for operation with different fuels, namely- natural gas, methanol, diesel, biogas, coal gas and hydrogen.

ii) Study the short term (e.g., few seconds) variations of wind and solar generated electricity to determine the fuel cell power plant capacity and response rate needed to match the load for stand-alone applications.

iii) Study the same variations listed above to evaluate how fuel cell power plants can help in improving the penetration levels of solar and wind power generator into the electricity grid.

iv) Cost-benefit analysis of PV/wind energy-fuel cell hybrid energy system capacity and the size of the load to be served. There may be an optimum size of the load to be served using this combination in a given location under the prevailing solar radiation and wind regime.

v) Study the remoteness factor of a site. In other words, if a site is very remote and difficult to access, the cost of delivering diesel fuel would be very high. In these cases the fuel cell power plant may be more valuable than the diesel engine because of lower fuel consumption and lower maintenance requirements. The cost-benefit analysis of the fuel cell power plant must take this factor into account.

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Senator BINGAMAN. Thank you, Professor. Please go right ahead.

STATEMENT OF DR. JOHN P. ACKERMAN, ASSOCIATE DIRECTOR, CHEMICAL TECHNOLOGY DIVISION, ARGONNE NATIONAL LABORATORY

Dr. ACKERMAN. Good afternoon. My name is John P. Ackerman. I am associate director of the chemical technology division of Argonne National Laboratory. I am responsible for Argonne's activities in the area of fuel cells.

It is a pleasure to appear today at the request of the subcommittee.

Many important benefits will result from this Nation's adoption of fuel cells, particularly of high temperature fuel cells that has the capability of making large intrusions in the markets that have been identified.

I would like to make the point today that research at universities and at national laboratories is badly needed if we are to realize these benefits.

Fuel cells are a new and fundamentally different way of making power from coal-derived fuels and other practical fuels. Fuel cells allow the clean and efficient use of coal and other fuels and provide a number of important operational advantages. We believe that these advantages will result in major benefits to the country in the economical production of energy and particularly as an item of international commerce.

Development of practical fuel cells should be vigorously pursued.

There are two broad classes of fuel cells; high and low temperature cells. The low temperature class includes the cells that have been used so successfully in space. Unfortunately, these cells are not suitable for use in the commercial world with practical fuels. This class also includes the phosphoric acid cells. Acid cells and other low temperature cells require extensive fuel processing subsystems, but they are now available for use in electric utilities, in smaller remote sites and in cogeneration.

Their market is primarily limited by the initial cost of the plant. The class of high temperature cells includes molten carbonate and solid oxide fuel cells. High temperature cells can process common fuels within the cells themselves. Plants designed using these cells can be simple and inexpensive.

They still require research and development but they could be ready for use in the early 1990's. The development of high-temperature cells is essential if we are to reap the full benefits of fuel cells.

The immense transportation sector is now served by combustion engines. Low-temperature fuel cell powerplants could provide attractive improvements in pollution and in fuel economy characteristics. Unfortunately, it would have unattractive weight and volume, would require introduction of a new fuel type, but mostly would cost so much that they are unlikely to find a significant market.

Of the advanced, high temperature fuel cell types, only the so-called monolith oxide fuel cells has the potential cost, weight, volume, and fuel capabilities to capitalize on fuel cell efficiency and pollution-free operation. This cell is being developed for initial ap-

plication in the "Orient Express" national aerospace plane, under the sponsorship of the Defense Advance Research Projects Agency.

Overseas programs emphasize carbonate fuel cells more than we do. Japanese corporate funding of carbonate fuel cells probably exceeds the total U.S. carbonate commitment. About twice as many people are working on carbonate fuel cells in Japan as in the United States. The government of the Netherlands has also recently announced a major new program in carbonate fuel cells.

Development of high-temperature cells has always been centered in industrial organizations in this country. For this reason, technology transfer from those programs that do exist in universities and at national laboratories has been highly effective. For example, among the developments in our own laboratories are, one, the entire concept of the monolith fuel cell that is being developed for defense application. It may make transportation fuel cells a reality and could dominate that market in time.

Two, the practical cathode material for carbonate cells. Three, the aluminizing coating that eliminated pernicious wet-seal corrosion and many, many others.

If desired, I have a longer list of those things.

Most of these developments would not be undertaken by mainstream industrial developers. There is a large and continuing need for this kind of independent fuel cell research. Our Federal programs have been highly effective in supporting the development by our manufacturers. They need to be equally effective in fostering the necessary independent university and national laboratory research.

Our technology in this country is still in the lead in every major fuel cell type. To maintain our present position of leadership in the face of a large and growing competition will require significant financial commitment by the manufacturers of the fuel cell and an increased research effort by universities and public research institutions.

In conclusion, substantial continuing Federal support of university and national laboratory research into particularly high temperature fuel cells is needed if this country is to reap the benefit that fuel cells offer.

Thank you.

[The prepared statement of Dr. Ackerman follows:]

Statement by Dr. John P. Ackerman
Associate Director, Chemical Technology Division
Argonne National Laboratory, Argonne, Illinois
Before the U.S. Senate Subcommittee on Energy Research and Development
February 24, 1986

Opening Statement

Good afternoon, Mr. Chairman. My name is John P. Ackerman. I am Associate Director of the Chemical Technology Division of Argonne National Laboratory, and am responsible for Argonne's activities in the area of fuel cells. It is a pleasure to appear today at the invitation of the Subcommittee. May I request, Mr. Chairman, that my full statement be made part of the record?

Fuel Cells are a new and fundamentally different way of making power from coal-derived gases and other practical fuels. Fuel cells allow the clean and efficient use of coal and other fuels and provide a number of important operational advantages. We believe that these advantages will result in major benefits to the country in the economical production of energy and as an item of international commerce. We further believe that development of practical fuel cells should be vigorously pursued.

There are two broad classes of fuel cells, high and low temperature. The low-temperature class includes the cells that have been used so successfully in space. Unfortunately, these cells are not suitable for use in the commercial world with practical fuels. This class also includes phosphoric acid cells. Acid cells and other low-temperature cells require extensive fuel processing subsystems. Phosphoric acid fuel cell power plants are available now for use in electric utilities, in small or remote sites, and in cogeneration. Their market is primarily limited by initial plant cost. The class of high-temperature cells includes molten carbonate and solid oxide cells. High-temperature cells can process common fuels within the cells themselves. Plants designed for them can be simple and inexpensive, allowing extensive application. They still require research and development, but they could be ready for use by the early 1990s. The development of high-temperature cells is essential if we are to reap the benefits of fuel cells.

The immense transportation sector is now served by combustion engines. Low-temperature fuel cell power plants could provide attractive improvements in pollution and fuel economy characteristics. Unfortunately, they would have unattractive weight and volume, would require introduction of a new fuel type, but mostly would cost so much that they are unlikely to find a significant market. Of the advanced, high-temperature, fuel cell types, only the recently conceived "monolith" oxide fuel cell has the potential cost, weight, volume, and fuel capabilities to capitalize on fuel cell efficiency and pollution-free operation. This cell is being developed for initial application in the "Orient Express" national aerospace plane.

Overseas programs emphasize carbonate fuel cells more than we do. Japanese corporate funding of carbonate fuel cells probably exceeds the total U.S. carbonate commitment. About twice as many people are working on carbonate cells in Japan as in the U.S. The government of the Netherlands has also recently announced a major new program in carbonate fuel cells.

Development of high-temperature cells has always been centered in industrial organizations. For this reason, technology transfer from universities and national laboratories has been highly effective. For example, among the developments that originated at Argonne National Laboratory are: (1) the monolith fuel cell that is now being developed for defense applications. It may make transportation and many other uses possible. (2) the practical cathode material for carbonate cells. (3) the aluminizing coating that eliminated pernicious wet-seal corrosion, and many others.

Most of these developments would not be undertaken by mainstream industrial developers. There is a large and continuing need for this kind of independent fuel cell research. Our federal programs have been highly effective in supporting development by our manufacturers; they need to be equally effective in fostering the necessary independent research.

Our technology is still in the lead in every major fuel cell type. To maintain our present technical leadership position in the face of large and growing competition will require significant financial commitment by manufacturers in the United States, and an increased research effort by universities and public research institutions.

In conclusion, Mr. Chairman, substantial continuing federal support of university and national laboratory research into high temperature fuel cells is needed if this country is to reap the benefits that fuel cells offer.

FULL STATEMENT

Fuel Cells are a radically new and fundamentally different way of making power from a wide variety of practical fuels including natural and coal-derived gases, petroleum distillates, and others. The fuel cell makes electricity directly from the chemical energy of its fuel, much as a battery makes electricity from the stored chemical energy of its electrodes. The difference is that fuel cells don't "run down" as long as fuel and air are supplied to them.

Fuel cells have several desirable characteristics: Fuel cell plants have been demonstrated to release exceptionally low levels of atmospheric pollutants, (several times lower than any anticipated standards) and they are quiet enough to be located near living and working areas. For example, 40-kW field-test power plants have been located in hospitals, apartment buildings, motels, nursing homes, and dormitories. Fuel cell power plants can be made in modules with very little penalty, because the cell's cost and efficiency are not dependent on size, as is the case with heat engines. Modularity presents major advantages in cost of capital and allows factory construction to improve quality control and reduce installation time.

Conventional heat engine power plants convert a fuel's chemical energy to heat, then convert the heat to shaft work, and finally convert the shaft work to electrical energy. Because of the direct conversion, and because limiting thermodynamic laws for fuel cells are different from those for heat engines, the limits on fuel cell efficiency are much higher. Despite many decades of development, today's heat engines can only reach efficiencies in the low to mid 40% range. The very first fuel cell plants have done that well, and reasonable plant designs having efficiencies of over 60% have been analyzed. Unlike convention plants, fuel cells retain high efficiency at partial load. This feature can be useful to utilities and other users.

Fuel cells fall into two broad categories: those low-temperature ($<1000^{o}F$) type that require either special fuels or complex fuel processing systems, and high-temperature ($1100-1800^{o}F$) cells that result in simple, inexpensive plants. The cells themselves are usually classified by the kind of electrolyte used to carry current through the cell. There are several kinds of cells, but the most important are:

1) The base electrolyte and polymer electrolyte cells, which have been used so successfully with high-grade reactants for space applications. We think that these cells are not suitable for use in the commercial world with common fuels.

2) The phosphoric acid fuel cell. This cell has a relatively low operating temperature, but is the most suitable for commercial use at present. Phosphoric acid fuel cell power plants ranging in size from about 1 kW up to 5 MW have been tested.

3) The high-temperature cells that are based on molten carbonate or solid oxide electrolytes. These developmental cells can process common fuels within the cell itself, and their high temperature of

operation means that they integrate well with the balance of the power plant. They offer the possibility of major cost reduction compared to present cells. There are two kinds of oxide cells; the "monolith" type is a more advanced, highly developmental device; a tubular design is being developed by Westinghouse.

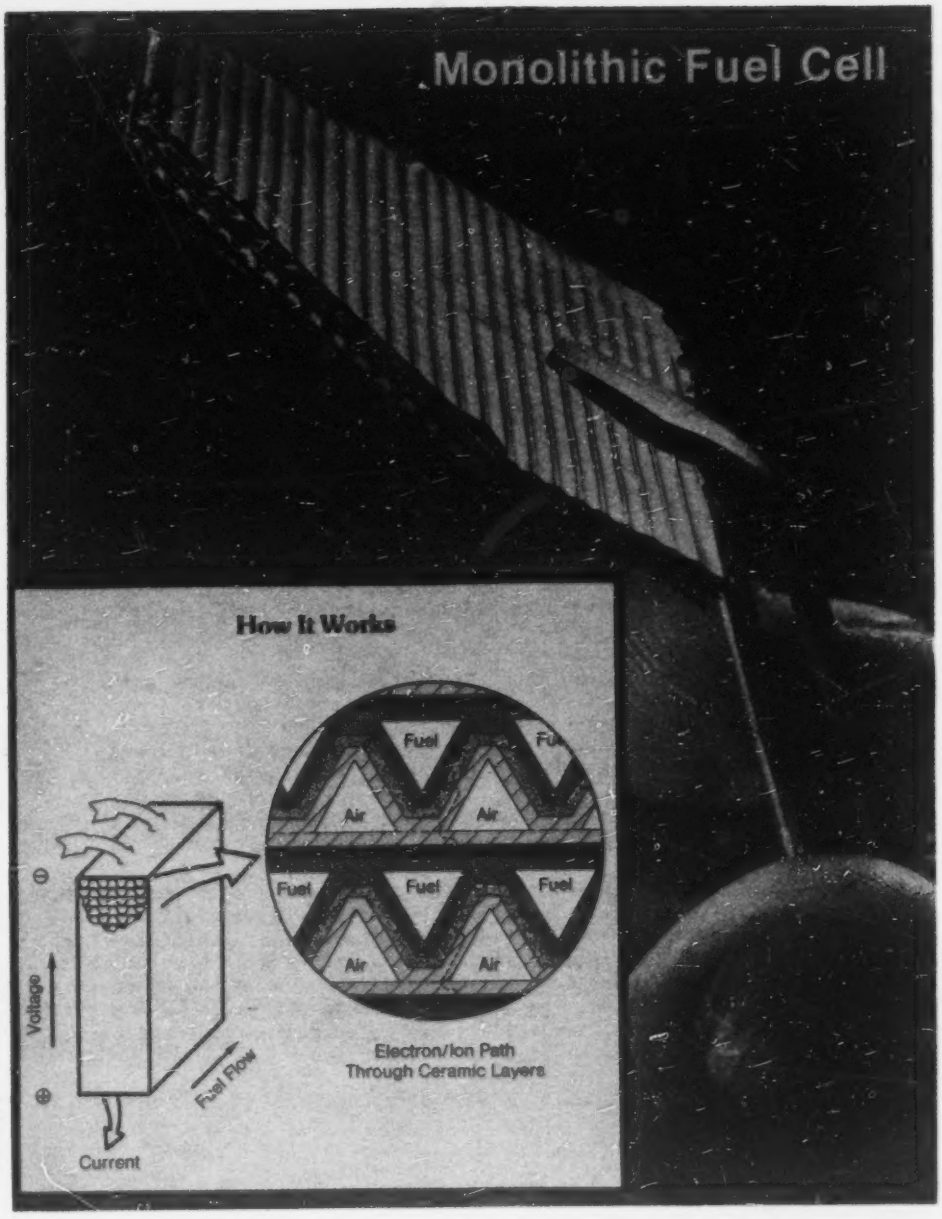
Applications for fuel cells include the space and military uses where fuel cells are often the power source of choice. These applications are usually met with highly specialized cells and fuels. Commercial uses fall into four broad groups: electric utility, generation of electricity and heat in small or remote sites ("on-site" applications), cogeneration, and transportation. Phosphoric acid fuel cells offer advantages to users in the first three categories; the extent to which they will find use is determined primarily by first cost of the installed plant, because the fuel cells are generally advantageous in other respects.

The transportation sector presents a formidable challenge to fuel cell developers. This market is being served by internal combustion engines that have very low costs and good weight, volume and reliability characteristics. Fuel cells could provide much better pollution and fuel consumption characteristics. Unfortunately, power plants based on low-temperature fuel cells would be unattractive on a weight and volume basis, would require introduction of a new fuel type, and would clearly cost so much more that they seem unlikely to find significant use. Of the high-temperature fuel cells, only the recently conceived "monolith" oxide fuel cell has the cost, weight, volume, and fuel capabilities to capitalize on fuel cell efficiency and pollution-free operation.

The monolith promises to simultaneously deliver more power and two to three times more mileage than an internal combustion engine of the same weight. It will operate on a variety of conventional fuels, including gasoline, certain coal-derived gases and liquids, jet fuel, natural gas, and alcohol. Pollution levels will be exceptionally low, as they are with other fuel cells. The monolith may begin to replace a significant portion of internal combustion engines in the 1990s; it could result in reneved U.S. domination of the automotive market.

The key to the monolith's performance is a one-piece structure made from high-temperature, ceramic materials arranged in the form of a honeycomb that has a small volume and a low weight. Since the materials double as both electrochemical and structural elements, a monolith fuel cell eight inches on each side would provide enough power to run a car. The fact that the fuel processing can occur within the cells themselves means that the entire power plant is similarly small, powerful, and simple.

Fabricating monolithic structures is a major challenge. The monolith structure requires placing four diverse ceramic materials only one-thousandth of an inch thick next to each other in a pattern that repeats itself some twenty times each inch. The small size and consequent lov resistance of the cells in that structure are responsible for its performance advantages, and for its very lov materials cost. The attached figure illustrates such a structure. The materials, some


Monolithic Fuel Cell
How It Works
Fuel
Air
Fuel
Air
Fuel
Fuel
Fuel
Air
Air
Electron/Ion Path
Through Ceramic Layers
Voltage
Fuel Flow
Current

very porous and others quite dense, must withstand operating temperatures of 1500 to 1900°F and fabrication temperatures several hundreds of degrees higher.

The tape casting methods that are being used to fabricate monolith structures are in wide use in the electronics industry and elsewhere; they are eminently suited to low cost and rapid production. The challenge is to integrate these methods with the structures and materials necessary for the fuel cell. Research and development have concentrated on modifications of materials that have proven successful in other oxide fuel cells.

The experimental program that has shown the fundamental feasibility of making monolith structures is being conducted for DARPA (the Defense Advanced Research Projects Agency of DOD) Initial application will be in the "Orient Express" national aerospace plane. Research on the monolith began in mid 1983. By 1984, two of the four materials had been successfully co-fabricated, then the first complete single cells were run, again ahead of schedule, above requirements, and below cost, in 1985. The most important early goal was the January 1986 operation of the completely integrated multi-cell structures that are unique to the monolith. Once again this goal was met, but considerable research remains before one can expect kilowatt-size modules that operate up to their full potential.

If the monolith can grow from its present early stage to a full-fledged power plant, its first practical uses are likely to come in high technology, high-cost applications such as aviation and space, or in utility and industrial applications where a high use factor would justify the likely cost of a new technology. Successful competition in the automotive marketplace seems probable after experience is gained from the initial applications, but the major economic impact of the technology will certainly occur there.

In each of the commercial categories except transportation, market-entry plants and stacks exist that are adequate on an operational and, in some cases, on an economic basis. Phosphoric acid plants have been built and have given acceptable field test experience in both 4.5-MW utility application (near Tokyo, Japan) and in dozens of 40-kW on-site plants worldwide. The fuel consumption of these plants is better than most conventional plants, and the experience suggests that reliability and other characteristics can become as good, too.

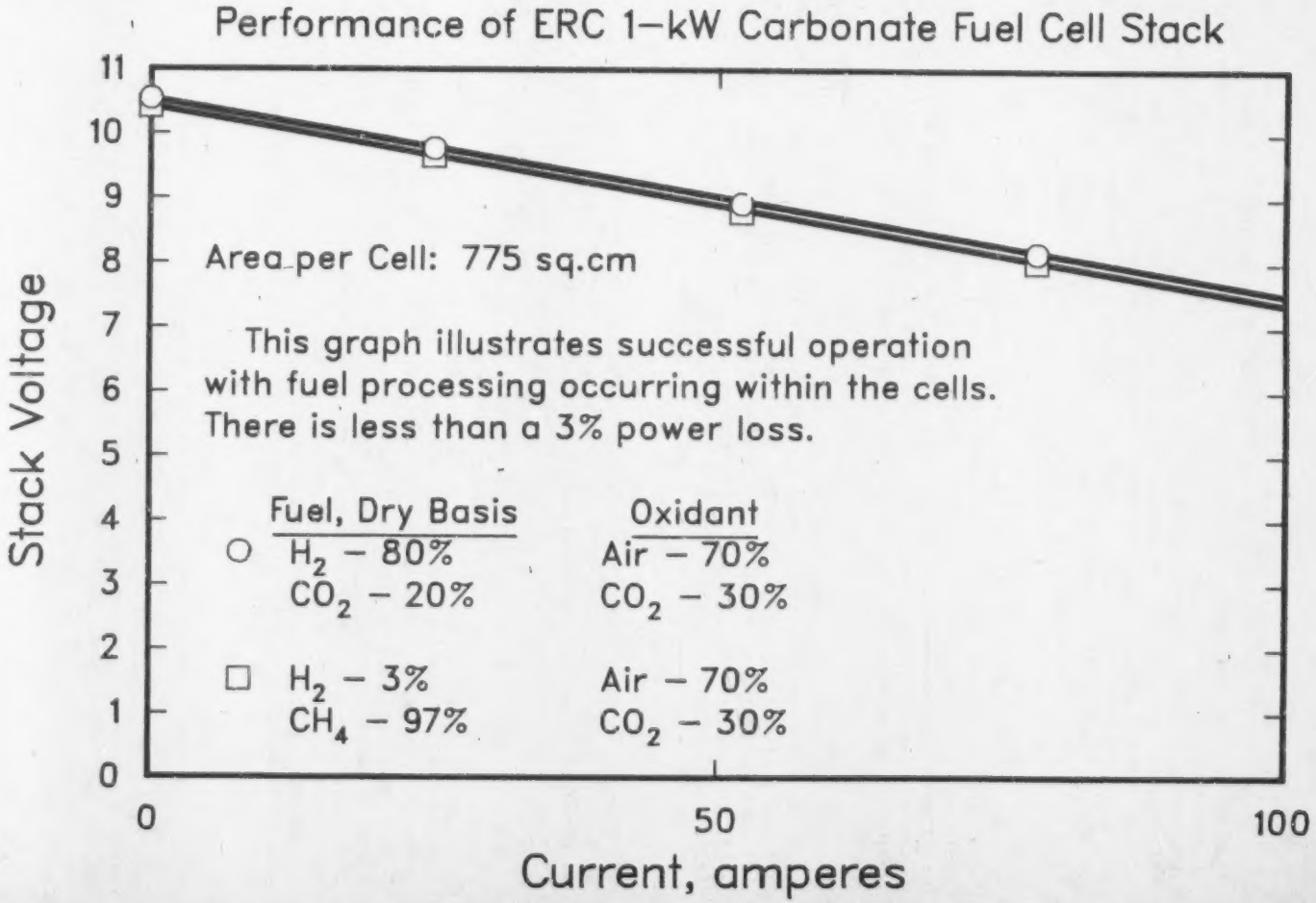
It appears that there must be a major reduction in plant complexity, and hence cost before there is extensive use of fuel cells. Some of that reduction will be generated by refinement of the phosphoric acid fuel cell plants and by the identification of applications where less complex phosphoric acid plants will suffice. Examples of such applications are those in petroleum and chlorine plants where by-product hydrogen is available. Development and use of the high-temperature fuel cells, however, can result in cost reductions and performance increases in a very wide range of utility, cogeneration, and on-site applications. That cost reduction is necessary to ensure that we reap the full benefits of our substantial commitment to the fuel cell option and our national lead in this area.

There are three technical reasons why high-temperature fuel cells lead to simpler and less expensive plants. First, for many fuels such as methane and light hydrocarbons, the need for the fuel processing subsystem is essentially eliminated. In the case of carbonate cells, a catalyst is inserted in the cell to accomplish that function. The attached graph shows a carbonate stack operating almost as well when processing methane internally as when using processed methane. Oxide cells may process fuel by using the anode material itself as the catalyst. The kinetics of the fuel processing reactions require temperatures in excess of 1000°F. Second, the second law of thermodynamics guarantees that heat is released in any energy conversion process. This heat is far more usable in the rest of the power plant equipment when it is available at high temperature. That advantage reflects in higher efficiency of the plant, fever and smaller heat exchangers, pipes, fans, valves, and so on. Third, for reasons of materials stability, high-temperature cells work better at high cell voltage than do practical low-temperature cells. This means a small advantage in intrinsic cell efficiency.

Calculations that were done by Argonne, but that are typical of those done by several other organizations, show that a coal fired utility plant using high-temperature cells would deliver electricity at 12% lower cost and at 16% higher efficiency than would its phosphoric acid counterpart. The corresponding number for gas-fired cogeneration favor high-temperature plants by 10% in cost of electricity delivered and 62% in electrical efficiency. Incidentally, these numbers clearly reflect the importance of initial plant cost.

Overseas programs tend to emphasize carbonate fuel cells more than we do. A large part of this difference in emphasis may come from our manufacturer's need to succeed with phosphoric acid plants. It appears that Japanese corporate resources applied to carbonate fuel cells may even exceed the total U.S. carbonate commitment. Five Japanese companies (IHI, Fuji Electric, Toshiba, Hitachi, and Mitsubishi Electric) have operated 1-kW stacks. They show enthusiasm and innovative designs that promise rapid advances. In our visits to the Japanese developers' plants and laboratories, it appeared that about twice as many people are working on carbonate cells in Japan as in the U.S. The government of the Netherlands has also recently announced a decision to begin a major fuel cell program in carbonate fuel cells. Both The Dutch and the Japanese programs are drawing heavily on published U.S. results and on cooperative agreements with U.S. companies. A carbonate fuel cell program appears to be starting in Italy; Sweden is evaluating a program in either oxide or carbonate cells.

U.S. manufacturers have been operating kilowatt level carbonate stacks for more than seven years and oxide cell arrays at the hundreds of watt level for about two years. Costs of cell materials and complexity of power plants are not generally of major concern in either kind of cell; fabrication costs may be. Scaleup to large sizes is not a particular issue in either technology; rather the programs have focused on solving critical problems in the minimum size device in order to avoid unnecessary expenditures.


Performance of ERC 1–kW Carbonate Fuel Cell Stack
Stack Voltage
11
10
9
8
7
6
5
4
3
2
1
0
Area per Cell: 775 sq.cm
This graph illustrates successful operation with fuel processing occurring within the cells. There is less than a 3% power loss.
Fuel, Dry Basis
Oxidant
○ H2 – 80%
CO2 – 20%
Air – 70%
CO2 – 30%
□ H2 – 3%
CH4 – 97%
Air – 70%
CO2 – 30%
0
50
100
Current, amperes

The issues that are being addressed in carbonate technology are generally related to life. Expected stack lifetime has risen to about a year and a half with the solution of problems in seal corrosion, electrolyte migration, and gas leakage in the cells. The new cathode material is expected to raise life expectancy to four or five years, which is the target range. In and beyond the four year range, there may be corrosion problems; that range has not yet been explored. Certainly there are also separate issues of fuel-processing catalyst longevity in the cell environment at times of one year and beyond.

Issues in oxide technology are not life-related as a rule, and there is very little worry about the fuel-processing performance of the cell. The major concerns are the reliability and cost of the manufacturing process. The concerns are in the same general areas, but of greatly different levels, for the monolith and the Westinghouse tubular oxide fuel cell concepts. Monolith concerns are greatest in the area of the feasibility of the manufacturing process; tubular cell concerns are greatest in the area of ultimate manufacturing cost.

In both technologies, the technical problems require sophisticated scientific attention; research of the kind done at universities and national laboratories has proven to be essential time and again. Some examples of contributions from our own laboratory are:

1) The whole "monolith" fuel cell concept and the proof of its feasibility, including all necessary activities -- concept invention, design, fabrication methods, materials composition and properties research. This development may be a direct result of the climate of responsibility assigned to the individual independent investigator in this national laboratory, combined with the ability to bring all the necessary scientific and basic engineering skills to bear.

2) The solution of the life-limiting wet-seal corrosion problem in carbonate cells. This is an example of a universally used solution that could as well have been done by a manufacturer. It was simply a relatively small byproduct of our effort to test other components in cells.

3) Identification of a suitable carbonate air electrode material and the proof that it will function throughout the required range of conditions. This particular piece of work required years of research, development of new research methodolgy and techniques, and painstaking fundamental scientific investigation into conduction mechanisms of ceramic semiconductors. Each of the industrial contractors began the work and eventually gave it up.

4) Elucidation of the relation between size distribution, shape, and concentration of particles in carbonate electrolytes and the physical properties of the electrolyte structure.

5) Determination of the growth rate of the various allotropes of the electrolyte ceramic phase particles in carbonate cells, and of the allotrope's stability regimes.

6) Determination of the mechanisms of undesirable gas mixing in carbonate cells, and the methods for measuring the rates of the several processes.

7) Methods to control electrode microstructure essential for understanding air electrode performance.

8) Appropriate syntheses for the electrolyte ceramic phase in carbonate cells.

9) Sintered electrolyte supports suitable for carbonate cells.

Most of these developments would not be undertaken by mainstream industrial developers. There are several reasons for this - nature of the organization, duration of the required effort, kinds of people involved, and other. There is a strong continuing requirement for a significant financial commitment by U.S. manufacturers, and for the mainstream development that those manufacturers do so well.

Clearly, there is also a large and continuing need for independent fuel cell research. It is, in fact, essential to maintaining the present U.S. position of technology leadership. With adequate independent research, we can be ready to test prototype high-temperature plants in the early nineties, and to capitalize on our strength in fuel cell technology.

Senator EVANS [presiding]. Thank you, Senator Bingaman, for starting. I apologize. There is a hearing in the Foreign Relations Committee, closed hearing on the very rapidly changing circumstances, as you might guess, in the Philippines. I can't bring you any news unfortunately from it, except to say that things are changing very rapidly. So whatever we learned an hour ago probably isn't true right now.

Dr. Berger, I understand you need to catch a plane home if the airports are still open by the time we get through and we would like to shift to you, and feel free, whenever you feel you have to leave, please go ahead—if you would like to testify now.

STATEMENT OF DR. MICHAEL E. BERGER, DEPUTY ASSOCIATE DIRECTOR, ALTERNATIVE ENERGY SOURCES, LOS ALAMOS NATIONAL LABORATORY

Dr. BERGER. Thank you, very much, Mr. Chairman, members of the subcommittee. Thank you for the invitation and the opportunity to testify on the subject of fuel cells.

At Los Alamos National Laboratory we have had a small but very intense fuel cell research activity since 1977. The focus of our research has been on transportation applications and is aimed at reducing fuel cell costs, increasing power output for a given volume and weight, and improved material. Although the research centers on fuel cells for transportation applications, it is also applicable to stationary fuel cells, as well.

We anticipate that an advanced fuel cell and fuel processor technology for transportation applications can be developed in about 5 years. For near-term bus applications, phosphoric acid fuel cell technology can be utilized in about 3 years.

We began our work on fuel cells based on the recognition of the potential benefits of this technology, which is the ability to produce electrical energy from a nonpetroleum-based fuel with exceptionally high efficiency, low pollution and low noise. Our work and the work of others confirm these benefits but we believe the full potential of the fuel cell concept remains to be realized.

Our program has received approximately $9.5 million from several sources since 1979, or a little more than $1 million per year. Our major sponsor has been the Department of Energy's Energy Storage Program, Office of Energy Storage and Distribution. This is a appropriate because of the synergism of the electrochemical research as applied to fuel cells and batteries. Other sponsors within the Department of Energy have included the Office of Transportation Systems, Electric and Hybrid Vehicle Program and the Fossil Energy Fuel Cell Program. We have also been asked to carry out studies for the Department of Defense, Department of Transportation's Urban Mass Transit Authority, and industry.

The studies for the Department of Transportation have concentrated on fuel cell bus applications and have been coordinated with both Georgetown University and the city of Albuquerque, NM.

As I stated, our major thrust has been in basic research and systems analysis, supporting fuel cells for transportation applications. In these applications, the fuel cell may eventually provide its largest payoff. Over 60 percent of U.S. usage and the majority of air

pollutants come from the transportation sector with its reliance on internal combustion engines.

Since we are looking at the future, we have based our program on the use of methanol as the transportation fuel of choice. Methanol is a means of storing hydrogen at high density and is gaining worldwide acceptance. Most importantly, methanol can be produced from coal, biomass or natural gas.

For vehicular applications, the characteristics high-power density, rapid start-up and low-cost features become increasingly important and our research in fuel cells has a focus on addressing these issues.

Our work in mobile fuel cells has led us to emphasize the proton exchange membrane or PEM fuel cell, which start at room temperature and runs efficiently at 200 degrees Centigrade.

This technology has demonstrated in the laboratory on small scale experiments high-power densities on the order of those required for an automotive application. PEM fuel cells feature a polymeric material as an electrolyte and because of their low-operating temperature, they have the potential for being manufactured with inexpensive plastic components.

Early in our program, we used our unique experimental and analytical tools to explain a number of performance mechanisms in phosphoric acid fuels. These tools include high-energy ion backscattering, computer averaged optical elipsometry and theoretical modeling on supercomputers, as well as a host of conventional chemical, electrical and analytical techniques.

We have used these tools to demonstrate an advanced electrode that can produce an overall 4 percent increase in fuel cell efficiency under typical operating conditions. We have also developed and demonstrated new electrodes which reduce the noble metal catalysts platinum content of the PEM fuel cell by over a factor of 10, without degrading performance.

We believe even further reductions will occur as we extend our approach, thus reducing the cost of the fuel cells significantly.

Preliminary results with an industrial subcontractor, using organometallic compounds as catalysts totally replaced noble metals, such as platinum, are also showing promise, although much more work needs to be done.

We have experimentally and analytically studied the catalytic mechanisms and heat requirements for the fuel processor or reformer, which decompose the methanol to provide the hydrogen for the fuel cell. Based on these results, we expect to demonstrate in the next few months a fuel processor which will be able to follow the sudden power demands required by vehicular applications and be of a size, weight, and cost compatible with these applications.

Finally, we have investigated the benefits of fuel cells as a power source for military vehicles where low noise and thermal signatures offer obvious advantages. When not powering the vehicle, the fuel cells could provide electricity for computers, firing systems, command, control, and communications systems. There are also many variations on this theme of fuel cell technology applications for mobile power that could benefit the rural areas of the United States.

Although we have achieved many successes in the laboratory to date, it is not conclusive that a fuel-cell-based transportation system can succeed against its older and more established competitors, but it is our conclusion that fuel cell technology contains the potential for a revolution in vehicular and mobile power sources.

It is our believe that the payoff is so high for the Nation in so many ways that a prudent investment in PEM fuel cell research aimed at vehicular applications is warranted during this period in which we still have time to capitalize on research successes.

For the PEM technology directed at mobile applications, we would recommend a research budget on the order of $4 million per year, over 5 years, to complete the research required to demonstrate a high-performance, low-cost fuel cell, compatible fuel processor using methanol as a fuel. We are confident that within this timeframe, and budget, the research and key material instructors can be completed producing the basis for a development program aimed at the high payoff, mobile and vehicular applications.

Thank you, very much. I will be glad to answer any questions that you have after the other people have spoken.

[The prepared statement of Dr. Berger follows:]

TESTIMONY

FOR THE

FUEL CELL RESEARCH PROGRAM AT LOS ALAMOS NATIONAL LABORATORY

Michael E. Berger
Deputy Associate Director
Alternative Energy Sources
Los Alamos National Laboratory

to

United States Senate
Committee on Energy and National Resources
Subcommittee on Energy Research and Development

February 24, 1986

The Los Alamos Fuel Cell Research Program is funded primarily by the U.S. Department of Energy, with complementary funding by the U.S. Department of Transporation and U.S. Department of Defense.

Mr. Chairman and Members of the Sub Committee, thank you for the opportunity to testify on the subject of fuel cells. At Los Alamos National Laboratory, we have had a small but intense fuel cell research activity since 1977. Although our focus has been on transportation applications, our research aimed at reducing fuel cell costs, increasing power output for a given volume and weight, and improving materials is directly applicable to stationary applications. We anticipate that an advanced fuel cell and fuel processor technology for transportation applications can be developed in five years. For bus applications, phosphoric acid fuel cell technology can be utilized in about three years.

We began our fuel cell work based on the recognition of the potential benefits of this remarkable technology: namely, the fuel cell's ability to produce electrical energy from a nonpetroleum-based fuel with exceptionally high efficiency, low pollution, and low noise. Our work and the work of others who are testifying today confirm these benefits, although we believe the full potential of the fuel cell concept still remains to be realized.

Our program has received approximately nine and one-half million dollars in funding from several sources since 1979 or a little more than one million dollars per year. Our major sponsor has been the Department of Energy's Office of Energy Storage and Distribution. This is appropriate because of the synergism of electrochemical research as applied to fuel cells and batteries. Other sponsors within the Department of Energy have included the Office of Transportation Systems (Electric and

Hybrid Vehicle Program) and the Fossil Energy Fuel Cell Program. We have also been asked to carry out system studies for the Department of Defense (Defense Advanced Research Projects Agency), the Department of Transportation (Urban Mass Transit Authority), and industry. The studies for the Department of Transportation have been coordinated with Georgetown University and the City of Albuquerque, New Mexico, and have focused on fuel cell bus applications.

By the 1970s with the successful fuel cell applications by NASA, the potential advantages of fuel cells for reducing the nation's dependence on petroleum was well recognized. However, there was no installed industrial manufacturing base, no large experience base from which to evolve advanced technologies, and there was much basic research still to be done. With the help of government funding, substantial progress has been made in developing fuel cells, particularly for utility and distributed electric power applications.

A portion of our research at Los Alamos has been to support this development. Early in our program, we used our unique experimental and analytical tools to understand the chemical reaction kinetics and evaluate performance degradation mechanisms in phosphoric acid cells. These tools include high energy ion backscattering, computer averaged optical ellipsometry, and theoretical modeling on super computers, as well as a host of conventional electrochemical and analytical techniques. More recently, based on our work in proton exchange membrane or PEM fuel cells,

we have demonstrated an advanced electrode that can be used in a phosphoric acid fuel cell to produce an overall 4% increase in fuel cell efficiency under typical phosphoric acid cell operating conditions.

Our major thrust, however, has been in basic research and systems analysis supporting fuel cells for transportation applications. In these applications, the fuel cell may eventually provide its biggest payoff. Over 60% of U.S. petroleum usage and the majority of air pollutants come from the transportation sector with its reliance on internal combustion engines. Since we are looking to the future, we have based our program on the use of methanol as the transportation fuel of choice. Methanol is gaining worldwide acceptance as a fuel and, most importantly, methanol can be produced from coal. Fuel cells can use methanol with much higher efficiency than internal combustion engines. Fuel cells, unlike internal combustion engines, maintain a high efficiency in the small 15-300 kilowatt sizes typically required for auto, truck, and bus applications. Fuel cell efficiency actually increases when operated at less than rated power as is typical in urban stop/go driving.

For vehicular applications, high-power density, rapid start-up, and low-cost become increasingly important, and our research in fuel cells has focused on these issues.

Our work in mobile fuel cells has led us to emphasize the proton exchange membrane or PEM fuel cell, which can start at room temperature and run efficiently at 100°C. In small scale laboratory experiments, this

technology has demonstrated high-power densities approaching those required for automotive applications. PEM fuel cells feature a polymeric material as an electrolyte, and because of their low operating temperature, they have the potential for being manufactured with inexpensive plastic components.

We have recently developed and demonstrated new electrodes that reduce the platinum catalyst content in this fuel cell by over a factor of 10 from previous configurations without degrading performance. We believe even further reductions will occur as we extend our approach, thus reducing the cost of the cell significantly. The prospect of replacing the noble metal catalysts with organometallic compounds has also been improved by work done under an industrial subcontract. Much more work remains to be done in this area.

We have initiated collaborations on advanced polymeric electrolytes with major manufacturers and are now confident that higher performance, lower cost polymers can be developed for this application. Samples suitable for testing in fuel cells should be available later this year.

One Los Alamos team member, in conjunction with Canadian colleagues at the University of Toronto, has experimented with conducting plastics that show promise for substantially reducing the cost of the bipolar plates, which are the main mechanical support elements for stacking the cells together.

We have experimentally and analytically studied the catalytic mechanisms and heat requirements for the fuel processor, or reformer, which decomposes methanol to provide hydrogen for the fuel cell. Based on these results, we expect to demonstrate in the next few months a fuel processor that will be able to follow sudden power demands required by vehicular applications and be of a size, weight, and cost compatible with those applications.

Our fuel cell research at Los Alamos has yielded a great deal of progress in the past few years. We are more optimistic than ever about the payoff that fuel cells will provide in the future.

Although we are now in a non-crisis situation relative to energy, we believe that prudent investments in fuel cell research should continue to be made so that the high-payoff research can be completed in a timely fashion. This allows for an orderly product development cycle. Manufacturing capacity for a field tested technology can be installed by the time worldwide petroleum reserves are depleted and an alternative mobile fuel becomes necessary.

For the proton exchange membrane technology directed at mobile applications, we would recommend a research budget on the order of four million dollars per year over 5 years. We are confident that within this time frame and budget the research required to demonstrate a high-performance, low-cost fuel cell and compatible fuel processor can be

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completed, leading to a development program aimed at the high-payoff mobile and vehicular applications. Even in this time of budget austerity, it should be possible to have a coordinated program with participation by the Departments of Energy, Transportation, and Defense.

Such a program would serve the national interest in several ways. If successful, a fuel-cell-based vehicular power source technology could establish world technological leadership for the U.S. in a key and widely applicable energy technology prior to the inevitable transition to non-petroleum fuel. The efficient use of U.S. coal-based methanol should provide employment for those in the U.S. coal and fuel industries, as well as U.S. chemical and automotive industries. For non-mobile applications, methane and hydrogen from biomass and other sources could also be utilized. Reduced pollution should help relieve the air quality crisis in our major cities while improving the Nation's overall health. Low-polluting, low-noise, fuel-efficient buses would benefit our cities and may be the most promising initial application for fuel-cell-based vehicular propulsion systems.

Finally, we have investigated the benefits of fuel cells as a power source for military vehicles where low noise and thermal signatures offer obvious advantages. When not powering the vehicle, the fuel cells could provide electricity for computers, firing systems, and command, control, and communication systems. There are also many potential mobile power applications of fuel cell technology that could benefit the rural areas of the United States.

Although we have achieved many successes in the laboratory to date, it is not a given fact that a fuel-cell-based transportation system can succeed against its older and more established competitors, but it is our conclusion that fuel cell technology contains the potential for a revolution in vehicular and mobile power sources. It is our belief that the payoff is so high for the nation in so many ways that a prudent investment in PEM fuel cell research aimed at vehicular applications is warranted during this period in which we still have time to capitalize on research successes.

Thank you. I will be pleased to answer any questions.

Senator EVANS. Thank you.
Father George.

STATEMENT OF REV. WILLIAM L. GEORGE, S.J., SPECIAL ASSISTANT TO THE PRESIDENT, GEORGETOWN UNIVERSITY

Reverend GEORGE. Thank you and thank you for the opportunity to testify. I am Father William George, the assistant to the president of Georgetown University. And in case your questions get too difficult, I have Dean Price back there, who is the university architect and physical plant director, who knows more about the technology than I do.

I know we have all heard a lot about fuel cells today. Half of my testimony is moot. We have discussed it all, so I will be extremely brief.

We have been working with Los Alamos for 1½ years to 2 years now on a feasibility study that would look into the fuel cell feasibility with vehicular applications. We have developed quite a relationship and we work very professionally and well together. We have also worked with a panel of experts in both the fuel cells and buses. So we have a lot of research and experience together.

Georgetown's experience has been mostly in the management and commercialization of various energy programs. We are looking at the possibility of developing a phosphoric acid hybrid fuel cell bus. We feel that in about 18 months, you could have a lab protype to develop your research information on, and in 4 years, actually be testing a minifleet.

We would like to ask the committee to consider that. It would cost about $9.5 to $11 million to complete the program. I did note that the Department witnesses mentioned that we are holding our own in fuel cell vehicles, and I would like to agree with members of this panel, that if we are going to hold our own, we need that last push to get things to where they are actually implemented and pretty much online and create the systems that will help the continued research and development of fuel cell vehicles.

So, Mr. Chairman, with that, I would like to thank you on behalf of Georgetown.

Senator EVANS. Thank you.

[The prepared statement of Reverend George follows:]

SENATE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Mr. Chairman and members of the Committee, I am Rev. William L. George, S.J., Special Assistant to the President of Georgetown University. With me is Mr. Dean Price, Georgetown University Architect and Director, Facilities Planning.

Thank you for the opportunity to testify on the subject of fuel cells. For the last year and a half Georgetown University, in association with Los Alamos Laboratories, has conducted a Fuel Cell Feasibility Study. A Blue Ribbon Advisory Panel of technical and policy making people in the Fuel Cell/Transportation Industry have participated. The names and associations of the participants on this panel are attached. The panel is in agreement that the potential benefits of using fuel cells in buses are tremendous; low-polluting, low-noise, fuel efficient buses would benefit our cities.

The technology for conducting Fuel Cell/Battery Bus operations is available for use today. The electric drive technology needed for fuel cell application is mature and has been utilized. Fuel cells of the Phosphoric Acid (PA) type are now being used in other applications for commercialization programs by several manufacturers in the U.S. and other foreign countries. There remains now the process of building a Fuel Cell/Battery Bus to prove the capabilities to potential users.

At this time, the PA type fuel cell is the most highly developed in terms of proven cell design concepts, has very low catalyst loadings, and has clearly defined manufacturing processes. In the present state of technology, it has a higher tolerance to CO, and the cost of the PA cell is lower than other cell types including the Proton Exchange Membrane Cell (PEM), primarily due to problems the PEM has in the current state of the membrane and catalyst loading technology.

The PEM fuel cells also are very promising, but it is expected that five to ten years could pass before it is ready for commercialization in a fuel cell bus program. In the meantime, it will be possible to demonstrate the commercial viability of a PA fuel cell bus and master the mechanical problems that transferring the fuel cells to vehicular applications will entail. By the time PEM technology is ready for direct application to a transit bus, timely application and expedited commercialization will be possible due to the experience of PA fuel cell buses. Since PA fuel cells are ready to go on line, necessary experience can now be gained through a program based on Phosphoric Acid fuel cell buses.

In consultation with industry specialists we have estimated that the commercial feasibility of a PA fuel cell bus system could be undertaken over the next four years. Georgetown University has a long history and experience in the field of energy demonstration projects leading to commercialization. We have recently concluded a major feasibility study in the field of fuel cell research. Georgetown also has a history of running a fleet of mini-buses in an urban environment. Georgetown University has unparalled experience in managing energy commercialization

programs. This fuel cell bus program would be managed by Georgetown in association with the Los Alamos National Laboratory which has been involved in fuel cell research for many years, and would operate in conjunction with the Department of Energy and the Department of Transportation.

The four-phase program that is envisioned would take place over four years and would have a total estimated project cost of $9.5 to 11 million. The details of the four-phase program are attached. Phase I would result in the first actual running hybrid fuel cell/bus prototype in the first 18 months. A prototype production line would be established and an additional three units would be put into operation over the next 18 months in Phase II. Pre-commercial production would take place in Phase III. As production facilities were established, another 10 fuel cell buses would be put into operation over the next 12 months. Phase IV includes continued demonstration support to bridge the emerging technology to actual commercial use.

The four-phase system is necessary to assure that the fuel cell/battery electric drive system is properly configured for the transit bus mission. Once installed, the Fuel Cell/Battery Bus would be subjected to performance and acceptance tests and be made ready for direct application in commercial service. Importantly, this investment will result in the actual manufacture and operation of fourteen fuel cell buses that will include private fuel cell company participation in a controlled manner.

It is important to push forward with not only the research of fuel cells, but the application of that technology in programs that actually promote the commercial viability of fuel cells. Someday, perhaps in the not too distant future, as a nation we will be thankful that we pushed forward with alternative mobile fuel development even though we were not in a crisis situation at the time.

On behalf of our President, Rev. Timothy S. Healy, S.J., thank you for this opportunity to testify.

Supplemental Information

Georgetown University has essentially completed a unique coal gasification fuel cell cogeneration study that has been developed by Georgetown/EBASCO in association with the Assistant Secretary of the Army for Research and Development.

With the final summary of the site feasibility studies now completed, we have concluded that each of the four sites, the Army Ammunition Plant in Scranton, Pennsylvania, Ft. Greely in Alaska, Ft. Hood in Texas, and the baseline site at Georgetown here in our Nation's Capital are all technically feasible and constructible, as well as environmentally acceptable. However, we do not think this project, as a four-site package, is economically feasible at this time, although two of the sites are potentially economically viable, namely the Scranton and Ft. Greely sites.

The Ft. Hood and Georgetown sites are economically infeasible at this time. This is due to the recent deflation of oil prices on the one hand, and the projected low avoided costs from the electric and gas utilities on the other.

Future refinements and improvements in these systems, combined with the rise in oil prices and demand for power that is efficient, and independently secure may perhaps change the scenario. The fuel cell study nevertheless has been, and will continue to be, a useful basis for the prospects of greater fuel efficiency with a respectable return on investment. This study stands as an essentially complete preliminary system design of coal gasification fuel cell cogeneration, and provides the methodology for financial development in the future. If the present price of gas and oil reverses itself with coal prices, this study becomes an essential and invaluable tool for the Department of the Army.

FUEL CELL FEASIBILITY STUDY

BLUE RIBBON ADVISORY PANEL

Dean Price	University Architect Georgetown University
Rev. William L. George, S.J.	Special Assistant to the President for Federal Relations Georgetown University
Sam Romano	Management Technology, Inc. Santa Barbara, California
Albert Sobey	Director, Energy and Advanced Product Economics General Motors
Terrance Kirkland	Consultant (Former Chief Army R & D Laboratories) Piedmont, South Dakota
Stanley Ruby	Acting Director Division of Energy Storage Technology Department of Energy
Dr. Johann A. Joebstl	Chief, Electrochemical Division STRBE-EC US Army Belvoir Research & Development Center
Daryl Jaschen	Chief Vehicle Engineer Washington Metropolitan Area Transportation Authority
Sherri Alston	Administrator Office of Mass Transit D.C. Department of Public Works
Glenn Coontz	Energy Division Manager City of Albuquerque, New Mexico
Gerry Green	P.T.I., Inc. Director Transportation Program

Senator EVANS. Dr. Topping.

STATEMENT OF PATRICK K. TAKAHASHI, DIRECTOR, HAWAII NATURAL ENERGY INSTITUTE, AND CHAIRMAN OF THE ENERGY AND RESOURCES DIVISION OF THE PACIFIC INTERNATIONAL CENTER FOR HIGH TECHNOLOGY RESEARCH, AS PRESENTED BY DR. DONALD TOPPING, DIRECTOR OF THE UNIVERSITY OF HAWAII SOCIAL SCIENCE RESEARCH INSTITUTE

Dr. TOPPING. Thank you. My name is Donald Topping. I am the director of the Institute of University of Hawaii's Social Science Research Institute, and I am presenting this testimony today on behalf of my colleague, Dr. Patrick Takahashi, who is the director of the Hawaii Natural Energy Institution and chairman of the energy and resources division of the Pacific International Center for High Technology Research.

The Hawaii Natural Energy Institute strongly supports the spirit and intent of S. 1686 and 1687, for fuel cells hold great promise for both stationary generation of electricity and onboard power to satisfy transportation requirements. These bills can provide the basis of the needed support for research and development, as well as testing and evaluation.

Fuel cells can contribute to the energy security of the United States and help our electric utilities provide quality power. This technology also offers another alternative to meet the Nation's transportation fuel requirement, especially as they can utilize fuels such as methanol produced from indigenous biomass and coal.

Hawaii is interested in fuel cells for use in both transportation and utility applications. Indeed, we have already initiated work on three related projects.

First, the HNEI has a range extender program for our 16 electric vehicles and have plans to utilize a phosphoric acid fuel cell on an EV van. The battery pack acts as a load leveler, with the power from the fuel cell being used to drive the EV, drawing supplemental power from the battery pack if needed, and recharging the battery pack when the drive train does not need the energy from the fuel cell.

A 5-kilowatt, methanol-powered fuel cell can add 50 to 80 miles to the range of the van. One bottleneck to wider scale utilization is that state-of-the-art fuel cell is not yet ready for commercial mobile applications. Some potential problems, such as the presence of carbon monoxide and unreacted methanol need to be addressed in order for this application to be fully successful for future large-scale use.

Presently, very little R&D funds are available to develop this option.

Second, HNEI has proposed a fuel cell for the wind energy storage test facility located at the Kahua Ranch on the island of Hawaii. The plan is to produce hydrogen from wind-generated electricity, store it in compressed form or in a hydride storage tank, and then use a fuel cell to generate electrical energy when the utility has a need for peaking energy or for electrical energy when the available wind-generated power is insufficient to meet the utility demand.

The hydrogen generation would primarily occur when there is excessive windpower for the grid. Signed windfarm contracts on the big island of Hawaii already approach 20 percent of the early morning, 3 a.m., demand lull, a level at which grid instabilities are feared.

Third, as part of the technology status assessment of hydrogen produced from renewable energy program, funded by the Department of Energy in cooperation with the utilities, HNEI could propose that a larger scale hydrogen-storage-fuel cell program be included in one of the strategies for a transition to greater use of hydrogen produced from renewable energy. Stationary fuel cells provide multiple fuel efficiency, storage, and environmental advantages that help reduce our dependence on imported oil.

The U.S. DOE Electric/Hybrid Vehicle Program has worked closely with HNEI and our EV Improvement Program is now one of only a handful of such supported centers. The renewable-hydrogen assessment program has shown that nearer term economic opportunities for a transition to greater utilization of hydrogen produced from renewable energy should be considered.

Federal support, however, is essential to solve the technical problems that are hindering wider acceptance of these options. The current drop in oil prices provides times to resolve these issues and S. 1686 and S. 1687 are the ideal means by which to accomplish the long-term goals for our Nation.

Thank you, Mr. Chairman. If you have questions, I will be happy to take them back to my colleague, Dr. Takahashi.

Senator EVANS. Thank you, let me first turn to Senator Bingaman for any questions you might have. You had the privilege of being here from the beginning of this afternoon. It is your first short.

Senator BINGAMAN. Thank you. I just have a couple questions of Dr. Berger, if I could. In your testimony on page 5, Doctor, you make a statement which seems to me sort of revolutionary, or at least exciting. You say, "We expect to demonstrate in the next few months a fuel processor that will be able to follow sudden power demands required by vehicular application and be of a size, weight and cost compatible with those applications."

That seems to me to be a fairly revolutionary type of breakthrough. Am I wrong, or is this something that is being generally done elsewhere?

Dr. BERGER. No, sir. We have at Los Alamos identified early on that fuel processor was one of the key research items that we should focus on. At the present time, fuel processor for a fuel cell on the order necessary to power an automobile is fairly large. It might be something on the order of perhaps 18 inches in diameter and three or four feet tall. That, of course, is not appropriate for consumer vehicles.

Through our internal supporting research moneys, we have designed and developed this fuel processor which we hope to test, very small, light compact and it basically takes advantage of some good engineering on our staff.

Senator BINGAMAN. Let me just ask you about the trend in the funding of this program that you are talking about. My information is that it has been decreasing since 1984. Is that accurate?

Dr. BERGER. That is correct.

Senator BINGAMAN. What level of funding is being proposed for this next year?

Dr. BERGER. In fiscal year 1987, the Department of Energy's controller's budget call, which we respond to, gave us an authorization or a target to shoot for of $700,000, which is about a 40 percent reduction over fiscal year 1986.

Senator BINGAMAN. Your statement indicates that at a level of $4 million per year for 5 years, you believe that what you are working on here could be developed to a point where it could have commercial application. Is that my understanding?

Dr. BERGER. Yes, sir.

Senator BINGAMAN. You also talk about the possibility of a coordinated program with Departments of Energy, Transportation, and Defense. Is the Department of Transportation or the Department of Defense—are either one of those involved in helping with this research at this time, financially?

Dr. BERGER. Senator Bingaman, in current fiscal year, fiscal year 1986, we are finishing up a study funded by the Department of Transportation, looking at fuel cells for bus applications and this program, as I mentioned, is coordinated with both Georgetown University and the city of Albuquerque is also assisting in some experimental data on their busses.

We had some funding in fiscal year 1984 and fiscal year 1985 from the Department of Defense. At the present time, do not have any funding from the Department of Defense, but there is a possibility that we may get some to run some experimental program later on this fiscal year.

Senator BINGAMAN. I would be interested, I guess, is there funding in either the Transportation Department proposed budget or Department of Defense proposed budget to help with any of this research?

Dr. BERGER. Not to my knowledge, no, sir.

Senator BINGAMAN. What is the $700,000 for 1987, how does that compare with the figure that you were at before the downward trend began in 1984?

Dr. BERGER. Senator Bingaman, I believe we peaked at about $2.8 million and this current fiscal year, we are still not sure what the budget is, as usual, but we think we are about $1.1 million. The $700,000 is considerably less than that. Even at $1.1 million, we have insufficient funds to involve the universities that we would like to involve to do some specialized research and to purchase hardware to our specifications from industry, also involving the industry in our program.

Senator BINGAMAN. So, it is fair to say that your funding has gone from $2.8 million, if the budget is adopted as proposed, down to $700,000 in a 3-year period, or essentially, you would be at 25 percent of your high.

Dr. BERGER. That is correct.

Senator BINGAMAN. That is all I have, Mr. Chairman.

Senator EVANS. Thank you. Let me start by going back to square one. In terms of automotive use of the fuel cell, you mentioned, and maybe Dr. Berger can respond to this, or anyone else for that matter. Fuel processor would be one of the major elements of such

an automotive system. What are the other major elements of the complete system?

Dr. BERGER. Mr. Chairman, there is fuel processor, there is the fuel cell stack, itself, then depending upon the configuration, there are other components. As with any other electric vehicle, one has motors, controllers and so on for driving the vehicle. One of the cleverer configurations that was arrived at by one of our earlier contractors, General Electric, which is now currently Hamilton Standard, which is a subsidiary of United Technologies—if we can keep all that straight—is that they also, with the fuel cell incorporated a small solid polymer electrolyte, which is their trademark for PEM type of technology, an electrolysis cell to produce a small amount of hydrogen that could be used for peaking. So there was a small hydrogen storage system on board that could then, when one needed acceleration, dump the hydrogen into the cell directly and get extra power for acceleration.

In addition, one would expect that you would need a battery for starting and perhaps in a bus application, you might have a series of batteries in a hybrid configuration, providing power for climbing hills or for acceleration.

Senator EVANS. A number of you have mentioned automotive uses of fuel cells. Can anyone tell me whether any of the American automobile companies show a considerable interest and are they willing to put up any research money of their own for what appears to be a potentially promising technology?

Dr. BERGER. Mr. Chairman, I will take a crack at that one, too. We have a fuel cell advisory board at Los Alamos that has been made up not only of representatives of the automotive industry, but representatives of the petroleum companies and companies introduced in producing methanol, as well as organizations such as the California Energy Commission.

The automotive companies have indeed shown considerable interest in the technology, but not to the point where they are willing to—they consider it sufficiently high risk and are not willing to invest their own funds. Recently, we have received a very small amount of funding from General Motors, mainly to provide staff time and travel to educate their staff and bring them up to speed on the technology and the opportunities that it offers.

Senator EVANS. Anybody else have any money on the line from the automobile companies, and this kind of research?

Seems to me, sometimes they want the research done and patented—well, they would like the patents, I guess, but have it ready to put in an automobile before they are interested. Is that a fair estimate of some of their attitude?

Dr. BERGER. Well, we have found one of the initial roadblocks in working with an organization like General Motors, is, of course, the patent issue and the intellectual property issues. It was quite interesting to see their lawyers get together with the Department of Energy lawyers and hash all this out. Not being a lawyer, I didn't quite understand what they were doing, but they finally seem to come to some conclusion, at least, initially so that we could work together.

Senator EVANS. Dr. Ackerman, you mentioned, I think in your testimony you were talking about only monolith oxide fuel cell

would have the potential for transport operation. Was that in conjunction with these large, new hypersonic aircraft, or was this just generally in terms of transportation?

Dr. ACKERMAN. No, sir. That is across the transportation field in general, including automotive, busses, trains, that sort of thing.

Senator EVANS. It seems to be at odds with some of the other testimony here.

Dr. ACKERMAN. Yes, sir. There is a definite difference of opinion here.

Senator EVANS. You think only these oxide cells will work. I guess Georgetown is at the point where you think phosphoric acid will work; Dr. Berger is in a membrane system.

You know, this morning we spent all of our time wondering how to get more money from a Department that doesn't seem to want to spend any, and now we are at a point how do we make a choice, or do we? Do we let the winners come out?

Dr. ACKERMAN. Senator, the economic requirements to compete with the internal combustion engine are terribly fierce in the transportation area. That includes aircraft and ground vehicles of all kinds—seagoing vehicles, as well. It is not a bad guess that the automotive transportation power system in your car costs from $25 to $50 per kilowatt and until you can compete on that economic basis, the market penetration that can be achieved is quite small.

There are initial market entry applications that can be done with conventional existing phosphoric acid or proton exchange membrane fuel cells, but that market is very small. If you are talking about taking over that market and you are talking about a worldwide dominance of our industry in the transportation field, my contention is that you need something very simple and very cheap. That is monolith.

Senator EVANS. So maybe it is not all as inconsistent as it appeared on the surface.

Dr. ACKERMAN. It is a question of extent of use.

Senator EVANS. It is sort of like, if you want to take over a government, don't you start a rebellion in the mountains, first?

Dr. ACKERMAN. Yes, sir.

Senator EVANS. You guys are the rebellion in the mountains? Or, maybe—from the technology that you are working on, does the phosphoric acid technology have any real chance of becoming cheap enough, light enough, reputable enough system for general transportation use, or is it going to be limited?

Reverend GEORGE. Senator, we are doing a study just to figure out the economic feasibility of the phosphoric or the PEM. The way I understand it, as a layman, that the PEM will be your ultimately—for vehicles, the way we are looking at it—the most financially rewarding. But in order to get there, you have to develop some research data on how the vehicles with fuel cells function. The mechanics, the electric-drive trains, all this kind of stuff, in use for a while, in a very controlled environment.

We feel that the phosphoric acid, you can find a near-term vehicle that can work and compare it to some of your diesel stuff, when that has proven—the mechanics, the PEM will be ready, and then you put in your new fuel cell after you have everything ready to receive it. It would spend up phosphoric acid moving along quickly,

it would speed the utilization of whatever fuel cell is used ultimately.

Senator EVANS. Is it accurate to say that all of those elements are common to whatever technology you are talking about; the drive trains and the others—transfer of whatever power you produce into automotive use, it would be essentially the same kind of power that you would be getting? Maybe some differences in peaking capacity or intensity of power?

Dr. ACKERMAN. Senator, once you have electric power, it is true, there is a great commonality. But in the process of getting to electric power, there is a very significant issue of how much equipment, besides the fuel cell, is required, and what is the size and cost of the fuel cell itself? In those areas, the technologies are not the same, but in the areas of the drive train, as you pointed, out they are very much the same.

Senator EVANS. When you say fuel cell, it is a fuel processor that you are talking about, Dr. Berger. Is that common between the various elements or is that part of the difference?

Dr. BERGER. I think the fuel processor is part of the difference. One of the things that you heard earlier this morning in some of the testimony were such things as direct-use fuel cells. In our case, the lower temperature fuel cells, as it was pointed out earlier, do require a fuel processor, at least initially. So that is one of the differences in the technologies.

Senator EVANS. Dr. Topping, you have had some experience at the University of Hawaii, have you not, with some vehicles?

Dr. TOPPING. There have been some experiments conducted there, yes. I am not intimately acquainted with them.

Senator EVANS. You pointed out the problems with the presence of carbon monoxide, some unburned or unreacted methanol. How significant and how common are those problems with essentially all of these fuel cells for transportation use?

Dr. TOPPING. Are you directing that to me, or members of the panel?

Senator EVANS. Yes, Dr. Topping. Well, you and then whoever else.

Dr. TOPPING. I would defer to other members of the panel. I cannot answer that. I am sorry.

Senator EVANS. OK. Anybody else? Dr. Ackerman.

Dr. ACKERMAN. Again, in high-temperature fuel cells, they can consume hydrogen, as do the low-temperature cells, but carbon monoxide and also hydrocarbons are fair game, they are fuel for these things and not poisons as they are in some of the noble metal, catalyzed, low-temperature systems.

Dr. BERGER. If I could add to that. Fuel cells such as the early space fuel cells, alkaline fuel cells, do not tolerate carbon monoxide and carbon dioxide well, and in these fuel cells, we say they poison the system and after a short amount of time, they cease to function.

Both the phosphoric acid fuel cell and the proton exchange membrane fuel cell are tolerant to these particular impurities.

Senator EVANS. Professor Rahman, it is an interesting combination, the techniques of utilizing fuel cells together with wind. What

is the optimum size of fuel cells, do you think, or have you gotten far enough along to——

Dr. RAHMAN. I have not gone far enough. That is what I said in my testimony, that we should do more research in finding out these issues before somebody decides to put a 5-kilowatt or 10-kilo-Watt fuel cell and see how it runs. But I think this has to be a demand-side question; how big a windmill do you need to serve certain load? Look at the load characteristics and then determine, can we serve that load using fuel cell and wind photovoltaic combination.

I think you should look at demand side first.

Senator EVANS. I have to keep looking back at testimony, as you went along. I think it was Dr. Topping, you talked about going from wind energy to develop hydrogen to then utilize for a fuel cell. Are there significant energy losses all along, so that that is an inefficient way to translate something like wind into the final energy form?

Dr. TOPPING. Once again, sir, I will have to relate this question to Dr. Takahashi, who can provide an answer.

Senator EVANS. We may in all cases have additional questions we would like to send in writing to you, and we will try to do that.

I am out of questions. It was a very interesting panel and it is obvious that this is a field of research that has many things going on, many different elements to sort out. It seems unfortunate that the Department of Energy has chosen to sort them out just by ignoring them, or essentially ignoring them. We will see what comes out of our hearings and then very quickly following it, of course, we will be into the budget recommendations that we may choose to make.

Thank you very much.

Finally, our last panel is Dr. Peter Blair, manager, Energy and Materials, Office of Technology Assessment, Fred Sissine, analyst in science and technology, Congressional Research Service, Dr. Richard Alkire, professor, chemical engineering department for National Research Council, University of Illinois.

Dr. Blair, would you like to begin?

STATEMENT OF DR. PETER D. BLAIR, PROGRAM MANAGER, ENERGY AND MATERIALS, OFFICE OF TECHNOLOGY ASSESSMENT, ACCOMPANIED BY PETER JOHNSON

Dr. BLAIR. Thank you, Mr. Chairman. Thank you, as well, for the opportunity to share with the subcommittee some of the findings of OTA's research studies as they relate to research and development needs and commercial prospects of fuel cell technology.

In the interest of time and lateness of the hour, I will summarize several of the points raised in the written testimony, but I presume the rest will follow in the record.

In particular, I will report on some of the findings of our assessment, "New Electric Power Technologies: Problems and Prospects for the 1990's," which was published last year.

Also, with me today is Peter Johnson, one of my colleagues, who directed a study resulting in a technical memorandum entitled

"Marine Applications for Fuel Cell Technology," which we released last week.

The earlier study examined the circumstances that could lead to substantial deployment of a variety of new electric power technologies, including fuel cells in the 1990's. The marine applications study reviews the state-of-the-art of fuel cell technology development and examines more specifically the commercial prospects for fuel cell systems in marine applications as shipboard power sources.

The purpose of my testimony today is to provide some insights from the analyses completed and underway at OTA that relate to the Senate Bills 1686 and 1687. Also, attached to my testimony is an appendix describing the characteristics of fuel cells and the fuel cell industry, which I really won't cover in the testimony.

At the current rate of development, initial commercial power generation applications for fuel cells could appear in the early 1990's. These fuel cells would be fueled primarily with natural gas. This large and potentially varied initial market, including both gas and electric utilities, as well as cogenerators, along with a variety of environmental and operational benefits, suggests that as cost of performance of fuel cell power plants research design goals, deployment could proceed rapidly.

The principal obstacle to widespread adoption of fuel cells, however, appears to be the high cost due to insufficient initial demand to justify the cost savings of mass production.

For such demand to appear in the 1990's, extensive commercial demonstration in the late 1980's would probably be necessary. The long term attractiveness of fuel cells is enhanced by the possibility of using alternative fuels, such as biomass or coal-derived gas. Indeed, one scenario is that a fuel cell can be employed as a kind of bridge between coal technology initially fueled by natural gas but amendable to biomass and coal-derived gas, as coal gasification and fuel processing technology matures.

The like cost of performance of such fuel conversion systems, however, appears to be still more uncertain than other fuel cell power plant components. So, the initial natural gas powered market for fuel cells is likely to move quickly as the technology matures, but the benefits of fuel diversity will only be realized with more development of fuel processing technology.

More generally, at the center of the policy debate over the future of electricity supply is the sort of mix of power generation technologies that will be deployed over the next several decades by utilities, or indeed, by the increased population of non-utility power producers. Those anticipating strongly resurrgent electricity demand in the 1990's argue in favor of continued commitments to large long-lead term plants, siting economies of scale that would in their view minimize long-term electricity costs.

Others, many of whom you have talked to today, who believe the demand growth to be far more uncertain, argue that flexible small capacity additions, including fuel cells as well as increased reliance on other methods of dealing with uncertain demands, such as conservation and load management is the more prudent and cost-effective path.

On one hand the insurance of smaller scale electricity supply could continue to be conventional oil and gas-fired combustion turbines, a sort of traditional short-lead time technology for utilities. The risk, of course, is returning to a past trend of increasing fuel costs which makes a turbines a very expensive option.

On the other hand, the small scale short lead time characteristic is one feature common to a range of new generating technologies, including fuel cells. The OTA new electric technology study examines the circumstances under which such technologies could play a significant role in electricity supply in the 1990's, perhaps to filling an insurance role against which claims may or may not be made.

Our study found, however, that ensuring the availability of such technologies in the 1990's would probably require sustained federal involvement in their commercialization. Fuel cells were among the new technology options found to be attractive for commercial deployment in the 1990's, but their use with other than gas is far less certain and will remain on the research and development agenda.

Senate bill 1686 addresses this agenda and to the extent that the need for fuel flexibility and fuel cell applications is found to be an important one, the research authorized in that bill acknowledges those research and development needs.

Our study also identified other options for accelerating the commercial development of new technologies. Included were revisions to existing federal legislation, including streamlined regulatory view, assistance in exploiting foreign markets and eligibility of exemptions under PURPA.

Development lead times for early commercial projects for new power technologies have often been longer than anticipated partially due to the time required for regulatory review. As regulatory agencies become more familiar with technologies and as their limited environmental impacts become know, the review process should become smoother and more predictable.

Senate Bill 1687 addresses these concerns by establishing Federal guidelines for fuel cell power plant licensing and permitting.

The pressures of competition from foreign vendors, many of which are heavily supported by their governments, as well as the current lack of U.S. demand for some of these new technologies, raise the concern over the continued commitment of U.S. firms to developing them.

Some domestics firms may not be able to compete in world markets over the next decade. However, success in those markets is important until fuel cell technologies can compete in U.S. grid-connected power generation market.

Senate Bill 1687 aids fuel cells which are integrated with renewable power technologies, which could increase U. S. competitiveness in foreign markets.

Finally, 1687 seeks to define fuel cell power plants as qualifying facilities under PURPA, whether or not they are implemented in cogeneration applications. If the aim is to accelerate early commercial applications of fuel cells, our analysis indicates that this would be an effective step.

However, it is important to note that it sets a precedent for broadening the base of qualifying technologies under PURPA.

To sort of sum up, if increased contribution to U.S. electric power generation of new electric power technologies is desired in the 1990's, OTA believes that while the current rate of development for some technologies is adequate, accelerated research, development and particularly demonstration for others will be required.

For fuel cells, the current rate of development of natural gas-based fuel cell powerplants is likely to result in the initial commercial applications in the early 1990's, although widespread deployment will depend upon the success of current demonstration efforts and early commercial applications.

Use of alternative fuels and fuel cells, however, is far less certain. If accelerated development of fuel diversity is considered important, Senate Bill 1686 and 1687 include provisions that effectively address this objective.

In addition, other provisions in these acts, such as the PURPA exemption, serve to accelerate the early commercial deployment of all fuel cell applications.

Senator EVANS. Thank you very much.

[The prepared statement of Dr. Blair follows:]

TESTIMONY OF PETER D. BLAIR
PROGRAM MANAGER, ENERGY AND MATERIALS
OFFICE OF TECHNOLOGY ASSESSMENT

before

Subcommittee on Energy Research and Development
Senate Committee on Energy and Natural Resources

February 24, 1986

Mr. Chairman,

Thank you for the opportunity to share with your subcommittee some of the findings of the Office of Technology Assessment's recent studies as they relate to the research and development needs and commercial prospects of fuel cell technology. In particular I will report on some of the findings of our assessment New Electric Power Technologies: Problems and Prospects for the 1990's, which was published last year. With me today is Mr. Peter Johnson, a Senior Associate at OTA, who directed a study resulting in a technical memorandum entitled Marine Applications for Fuel Cell Technology, which was released last week.

The earlier study examined the circumstances that could lead to substantial deployment of new electric power technologies, including fuel cells, in the 1990's. The Marine Applications study reviews the state-of-the-art of fuel cell technology development and examines more specifically the commercial prospects for fuel cell systems in marine applications as shipboard power sources. The purpose of my testimony today is to provide

some insights from the analyses completed and underway at OTA that relate to S. 1686 and S. 1687. Attached to my testimony is an appendix describing the characteristics of fuel cells and the fuel cell industry which I won't cover in my testimony.

INTRODUCTION

A fuel cell, like a battery, produces electricity by an electrochemical reaction. In fuel cells, it is a reaction between hydrogen, supplied by a hydrocarbon fuel, and oxygen. Neither combustion nor moving parts are required in the conversion process. Fuel cell power plants are expected to generate electrical power very efficiently and with modest environmental impacts when compared to those of combustion technologies. Fuel cell installations have the potential of being deployed economically in a wide variety of sizes, ranging from small cogeneration units to eventually large central power stations. In addition, they can be installed in many locations, including areas where both available space and water are limited. Among the other advantages which have attracted strong interest among potential investors are:

--responsiveness to changes in desired output

--short construction lead times

--easily recovered waste heat

--low noise

--fuel flexibility

--modular design

--factory component fabrication

--unattended operation

At the current rate of development, initial commercial power generation applications for fuel cells could appear in the early 1990s; these fuel cells would be fueled primarily with natural gas. This large and potentially varied initial market (including both gas and electric utilities as well as cogenerators), along with the environmental and operational benefits cited above, suggests that as cost and performance of fuel cell powerplants reach design goals, deployment could proceed rapidly. The principal obstacle to widespread adoption of fuel cells, however, appears to be high cost due to insufficient initial demand to justify the cost savings of mass production. For such demand to appear in the 1990's, extensive commercial demonstration in the late 1980's will probably be necessary.

The long term attractiveness of fuel cells is enhanced by the possibility of using alternate fuels such as biomass or coal derived gas. Indeed, a fuel cell is likely to be employed as one of the "bridge" clean coal technologies, initially fueled by natural gas but amenable to coal derived gas, as coal gasification and fuel processing technology matures. The likely cost and performance of fuel conversion systems such as coal to gas are still more uncertain than other fuel cell powerplant components. The initial natural gas powered market for fuel cells is likely to move very quickly as the technology matures, since the benefits of fuel diversity will only be realized with more development of coal conversion other such technologies.

COMMERCIAL PROSPECTS FOR THE 1990'S

Most of the commercial demonstration plants crucial to the future of the fuel cell will not begin operations until the late 1980's, though a 4.5 MWe demonstration plant is operating successfully in Japan and a number of 40-KWe demonstration units are operating in the United States.

The level of eventual commercial deployment depends heavily on the success of these demonstration units; the period of time deemed necessary to generate investor confidence; and the willingness of the vendors to share the risk and cost of the early units. The perceptions and decisions of investors, vendors and buyers cannot be accurately and confidently predicted, but current evidence suggests that the early 1990's may see the beginnings of fuel cell mass production and the first commercial applications. As much as 1,200 MWe of capacity of fuel cell power units may be operating by 1995.

Low production levels will drive installed capital costs down somewhat, but they will remain far above costs in a mature market, i.e. with high production. Mass production is unlikely to occur until a sizeable market is anticipated--in the mid-1990's at the earliest. Such a market may develop as potential buyers observe the continued operation of the demonstration units and the initial operation of the early commercial installations.

Extremely important to prospective buyers will be operating and maintenance costs, economic life, and reliability. In particular, they are

likely to be sensitive to the rate at which fuel cell performance degrades over time under various operating conditions as well as to the cost and difficulty of replacing cells when their performance becomes unacceptable. There is uncertainty among potential users over these two points, both of which are crucial to the fuel cell's ultimate commercial prospects. Should problems be encountered in either area in early commercial prototypes, commercial deployment will be delayed. If power plant operation is favorable, subsequent market growth in the latter half of the 1990's could be very rapid.

STEPS FOR FUEL CELL DEVELOPMENT AND S. 1686 and S. 1687

At the center of the policy debate over the future of electricity supply is the mix of power generation technologies that will be deployed over the next several decades by utilities or by the increased population of non-utility power producers. Those anticipating strongly resurgent electricity demand in the 1990's argue in favor of continued commitments to large central-station power plants. They cite economies of scale of such plants that, in their view, would minimize long term electricity costs. Others, who believe demand growth to be more uncertain, argue that flexible small-scale capacity additions, including fuel cell power plants, as well as increased reliance on other methods of dealing with uncertain demand such as conservation and load management is the most prudent and cost-effective path.

In the event of greatly accelerated electricity demand growth, and continued problems in building conventional, central station powerplants,

serious difficulty in meeting new demand in the 1990s may be encountered. Under such circumstances, our new electric power technologies study found that it would be prudent to ensure the availability of an array of new generating technologies, in effect, investing in the insurance of technologies to provide flexibility in making investment decisions in an uncertain demand growth environment. Buyers of generating technologies would then have a broader range of technologies from which to choose. Indeed, seeking diversity in electricity supply options is being pursued by both utilities and nonutility power producers to cope with the variety of future uncertainties, such as more stringent control of air pollution emissions or increased availability of natural gas.

On one hand, the insurance of smaller scale electricity supply technologies could continue to be conventional oil- and gas-fired combustion turbines, a traditional short lead-time technology for utilities. The risk is, of course, returning to a past trend of increasing fuel costs, which makes turbines a very expensive option. On the other hand, the smaller-scale, short lead time characteristic is one feature common to a range of new electric generating technologies, including fuel cells. The OTA new electric technologies study examined the circumstances under which such technologies could play a significant role in U.S. electricity supply in the 1990's -- perhaps fulfilling an insurance role, against which claims may or may not be made.

Our study found, however, that ensuring the availability of such technologies by the 1990's will probably require a sustained Federal involvement in their commercialization. Fuel cells were among the new

technologies options found to be attractive for commercial deployment in the 1990's. While the progress toward commercial deployment of natural gas fuel cell power plants appears to be well underway, their use with alternative fuels is far less certain and will remain on the research and development agenda. S. 1686 addresses this agenda and to the extent that the need for fuel flexibility in fuel cell applications is found to be important, the research authorized in that bill acknowledges the research and development needs.

Our study also identified other options for accelerating the commercial development of new electric power technologies. Included were revisions to existing Federal legislation, including streamlined regulatory review, assistance in exploiting foreign markets, and eligibility for exemptions under PURPA.

Development lead times for early commercial projects new power technologies have been longer than anticipated, partially due to the time required for regulatory review. As regulatory agencies become more familiar with the technologies, and as their limited environmental impacts become known, the review process should become smoother and more predictable. If there is accelerated demand growth, however, it may be necessary to reduce these lead times to avoid power shortages. Action to educate regulators about each technology's impacts in the course of demonstrations might reduce the lead times of early commercial units. S. 1687 addresses these concerns by establishing Federal guidelines for fuel cell power plant licensing and permitting.

The pressures of competition from foreign vendors, many of which are heavily supported by their governments, as well as the current lack of U.S. demand for some of these new technologies in grid connected power generation applications, raises the concern over the continued commitment of U.S. firms to developing these technologies. Some domestic firms may not be able to compete in world markets over the next decade. However, success in those markets is important until fuel cell technologies can compete in the U.S. grid-connected power generation market. S. 1687 aids fuel cells which are integrated with renewable power technologies; this could increase U.S. competitiveness in foreign markets.

Finally, S. 1687 seeks to define fuel cell power plants as qualifying facilities under PURPA, whether or not they are implemented in cogeneration applications. If the aim is to accelerate early commercial applications of fuel cells, our analysis indicates that this would be an effective step. It, however, sets a precedent of broadening the base of qualifying technologies under PURPA.

CONCLUSIONS

If increased contribution to U.S. electric power generation of the new electric power technologies is desired in the 1990's, OTA believes that while the current rate of development for some of these technologies is adequate, accelerated research, development and, particularly, demonstration for others would be required. For fuel cells, the current rate of development of natural gas-based fuel cell power plants is likely to result in initial commercial applications in the early 1990's, although

widespread deployment will depend upon the success of current demonstration efforts and the early commercial applications. Use of alternative fuels in fuel cells, however, is less certain. If accelerated development of fuel diversity is considered important, S. 1686 and 1687 include provisions that effectively address such an objective. In addition, other provisions in these acts, such as the PURPA exemption, serve to accelerate the early commercial deployment of all fuel cell applications.

APPENDIX

Cost and Performance Characteristics and Industry Outlook[1]

FUEL CELLS: A BASIC DESCRIPTION

The typical fuel cell power plant will consist of three highly integrated major components: the fuel processor, the fuel cell power section and the power conditioner. The fuel processor extracts hydrogen from the fuel which can be any hydrogen-bearing fuel, though most installations in the 1990's are expected employ natural gas.

The hydrogen is then fed into the fuel-cell power section, the heart of which are "stacks" of individual fuel cells. The cells are joined in series (the stacks), which, in turn, are combined to form a power plant. There are several types of fuel cells being developed. These are categorized according to the type of electrolyte--the medium in which the electrochemical reaction occurs--they use. The first-generation fuel cells use phosphoric-acid as an electrolyte. These cells are the most developed and are likely to account for most of the fuel cells deployed in the 1990's.

Other less mature, fuel cell designs which employ alternative electrolytes promise superior performance; molten carbonate cells are the closest to commercial application, but are not expected to be commercially deployed until the late 1990's at the earliest. They therefore are not likely to account for an important share of fuel cell power plants installed in the 1990's.

The electric power that flows from the fuel cell stacks is direct current. With some voltage regulation, this dc power can be used if the load is capable of operating with direct current. Otherwise, a power conditioner is required to transform the direct current into alternating current. This allows it to be fed into the electrical grid and to be used by alternating-current electrical motors.

The components of the fuel cell plant are tightly integrated to reduce energy losses through the proper management of fuel, water and heat. Various parts of the plant benefit from the byproducts of other parts of the installation resulting in overall conversion efficiencies of 36 to 44 percent. Further efficiency gains result when byproduct heat from different parts of the plant are tapped for external use. The fullest exploitation of the fuel cell's heat may yield total energy efficiencies of up to 85 percent for the entire plant. The heat can be used for domestic hot water, for space heating, or to provide low-level process heat for industrial uses.

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1. Abstracted from U.S. Congress, Office of Technology Assessment, New Electric Power Technologies: Problems and Prospects for the 1990's, OTA-E-246, July 1985 and Marine Applications for Fuel Cell Technology, OTA-TM-O-37, February, 1986.

COST AND PERFORMANCE

The expected cost and performance of typical fuel-cell power-plants for the reference year 1995 are summarized in Table 1. The units deployed in the 1990's probably will be built around two sizes of fuel cell stacks. The larger stacks are likely to be capable of generating approximately 250-700 KWe (gross, dc) each and the smaller stacks about 200-250 KWe (gross, dc) each. The plants built around the small stacks will be installed mostly in large multi-family dwellings, commercial buildings and in light industries; most will probably be used to cogenerate both electricity and useful heat. The typical system would consist of at least two complete self-contained modules, each of which might produce about 200 KWe (net, ac).

Plants using the larger fuel cell stacks most likely will be deployed primarily by electric utilities, and by industries which would use them in cogeneration applications. Installation capacities probably will range from several megawatts on up. The reference installation used in OTA's analysis is 11 MWe (net). Many of the major components would be fabricated in factories and shipped to the site on pallets.

The lead time of a small fuel cell power plants should be about two years. These units are relatively small, unobtrusive, and quickly and easily erected. Modules subsequently added at the same site could require as little as a few months. Regulatory delays are unlikely because of relatively minor siting and environmental considerations.

Installations utilizing the larger stacks, however, may encounter more serious regulatory problems. Unlike the approximately 480-600 square feet required by an installation of two, 200-KWe units, an 11 MWe installation would occupy about 0.5-1.2 acres of land. Because the plants frequently may be located in the midst of populated areas, the opportunity for regulatory conflicts with these larger plants is considerably greater. Partly offsetting these factors, though, are the environmental advantages associated with fuel cell power plants. Hence, a lead time of three to five years is anticipated with the larger units, considerably longer than the small plant's lead time, but also much shorter than that of most conventional power plants. As with the smaller fuel cell installations, capacity subsequently added to an already existing fuel cell plant should require considerably shorter lead times.

The operating availability of large fuel cell power plants may range between 80 and 90 percent. Availability is heavily dependent on the quality of design--its simplicity, the extent to which it has redundant components, the number of parts and their reliability--and on the availability of spare parts and repair people when they are needed.

The fuel cell can be applied to any duty cycle. The fuel cell has excellent load following capabilities and high efficiency over a wide variety of operating levels.

The fuel cell power plant's lifetime is assumed to be approximately 20 to 30 years with periodic overhaul of the fuel cell stacks and other components. Over time, the power plant's efficiency drops. The timing of overhauls will vary; schedules will be a function of the performance reduction over time and of other factors such as the cost of fuel. In some cases the stacks must periodically be removed and replaced with new ones. The old unit then is shipped back to a manufacturing plant where its catalyst (in the fuel processing section) and perhaps other components are removed, processed and recycled. While the overhaul schedule and costs are uncertain, it is assumed here that all stacks are replaced after the equivalent of 40,000 hours of operation at full capacity.

Efficiencies (based on higher heating-value) for large fuel cell plants are expected to be between 40 and 44 percent. Small plants may have efficiencies of approximately 36-40 percent. The estimated efficiencies are those which might characterize a plant over its lifetime; efficiencies of new stacks could be higher while those of older stacks might be below that level.

The installed capital costs of fuel cell power plants are expected to range from $700-3,000/KWe for large units to $950-3,000/KWe for small plants; expected values for 1995 are $1,430/KWe and $2,240/KWe respectively. The low numbers can be expected where units are commercially produced in large numbers; the high numbers are representative of prototype units and include non-recurring costs. By far the largest expense is the fuel-cell power section itself; it is expected to account for about 40 percent of the costs of a mature 11 MWe plant. The largest decrease in capital costs over the next decade will come from increases in the levels of fuel-cell production. However, technical improvements in the fuel cell plant itself may substantially reduce costs as well. Already, over the past several years, design changes have reduced costs by an appreciable amount.

Operating and maintenance costs may range between 4.3 and 13.9 mills/KWh. The biggest element in O & M costs is the cost of periodically replacing cells stacks. For specific applications, the actual O & M costs will depend on the overhaul period for the cell stacks and the material and labor costs for each overhaul.

Fuel costs are expected to be approximately 27-33 mills/KWh, accounting for the major portion of electricity costs from fuel cells. Fuel costs also constitute the fuel cell's greatest advantage over some of its competitors such as the gas turbine, due to the fuel cell's high efficiency which yields substantially lower per KWh fuel costs. Major variations in fuel costs per KWh will result primarily from fluctuations in fuel prices. Fuel cell efficiency variations, due to technical improvements or maintenance practices (especially stack reloading schedules), also would be reflected in different fuel costs. In the longer term, post-2000, it is expected that natural gas will have to be replaced with more abundant fuels. Primary candidates are synthetic fuels--especially methanol--from coal and biomass.

Stacks are of central importance in determining capital, O & M, and fuel costs. The development and extended demonstration of cheap (per KWe) and reliable stacks which can operate at high efficiencies for extended periods are critical to the success of the technology. Technological improvements which could be especially important in this regard are the development of inexpensive, corrosion-resistant cell structural materials and less expensive and more effective catalysts to operate at higher pressures and temperatures, and improved automated fabrication and handling processes for large area cells. Also important is the development of cheap, reliable and efficient small-scale reformers (fuel processing units) and the improvement of various other standard components.

THE FUEL CELL INDUSTRY

The current major efforts to develop the fuel cell for grid-connected applications in the United States are split between natural gas and electric utilities. The electric utilities are pursuing the use of fuel cells in central station applications, while gas utilities have concentrated on relatively small, "on-site" fuel cells which would increase markets for natural gas.

The initial commercial impetus behind fuel cell development in the United States was the space program in the 1950's and 60's. Efforts to develop fuel cells for terrestrial applications multiplied during the mid 1960's, but by the end of the decade most had ceased with one notable exception. In 1967 a group of gas utilities formed an organization, the Team to Advance Research on Gas Energy Transformation (TARGET), to develop equipment that somehow could counter the electric power industry's capture of the gas industry's markets. This and subsequent programs culminated in the current effort in which the Gas Research Institute (GRI), funded by the gas industry, and the DOE are deploying and testing a number of 40-kWe fuel cell cogeneration units. Several units of this size also were installed in Japan. Concurrently, GRI and DOE are funding a coordinated multi-year research project expected to yield an "early entry" onsite fuel cell system with an expected output of about 200-400 kWe.

Meanwhile, since 1971, fuel cell manufacturers and electric utilities established the Fuel Cell Users Group, an association established about five years ago. The group, now consisting of over 60 members, works closely with EPRI, fuel cell vendors and others to promote the use of fuel cells among electric utilities. This group, along with the Electric Power Research Institute, the Federal government and others have sought to develop and deploy multi-megawatt fuel cell power facilities. By 1978, a 4.5 MWe project was initiated in New York City. The New York unit suffered from delays in gaining local regulatory approval. These delays exceeded the storage life of the power section so that the unit could not be operated without refurbishment. As a result, the project was abandoned in 1984. Another similar, but improved unit was installed in Japan. That unit, made by the same manufacturer which produced the New York installation, has operated very successfully since April 1983. Currently, plans are being laid both in the United States and in Japan to first develop and deploy commercial demonstration units, and then to initiate

commercial production of fuel cells late in the 1980's or during the early 1990's.

In the recent years a number of cooperative agreements between Japanese and U.S. firms have evolved, perhaps the most important of which is the joint venture between United Technologies and Toshiba. The two companies have agreed to cooperative electric utility commercial power plant design and development activity.

Government involvement on both sides of the Pacific has been extensive. In the United States, Federal funding has been divided between military/space applications and support of civilian commercial uses. The support for civilian applications has emphasized the use of fuel cells in transportation and in electric power generation; this support has emanated from the DOE and its predecessor agencies. The DOE program of greatest importance to the near-term commercial prospects of the fuel cell is the Phosphoric Acid Fuel Cell Program. The National Aeronautics and Space Administration (NASA)-Lewis Research Center has been designated by DOE as the lead center for the program.

DOE's funding for fuel cells is summarized in Table 2. DOE's support peaked in 1984, when $42.6 million were spent on the technology. A very substantial portion of the funds has been dedicated to the phosphoric acid technology--which is the most promising technology for initial commercial penetration. While DOE spending on fuel cells dropped only slightly in FY '85, substantial reductions has been proposed for subsequent years. Under the latter proposal, support for the phosphoric acid technology is eliminated altogether.

Although some fuel cell research and development took place in Japan during the 1960's and 1970's, the current Japanese fuel cell program did not materialize until 1981. At that time, under the aegis of the Ministry of International Trade and Industry (MITI), the agency's "Moonlight Project" initiated a coordinated program directed towards the development of fuel cell technologies for various applications. All of the Japanese equipment manufacturers are working under this program, as are several Japanese utilities.

While the Japanese have in the past lagged behind the U.S. program, it appears that the current Japanese program has narrowed the gap. This results in part from the attentive observation of and participation in U.S. efforts. The Japanese have learned from U.S. successes and mistakes, while providing their own refinements and modifications.

Industry Outlook and Major Impediments

The fuel cell industries in both the United States and in Japan are positioning themselves for substantial commercial deployment of fuel cells in the 1990's. At the cost and performance levels which the fuel cells may achieve, extensive markets for both central station and dispersed applications could develop.

Deployment in Japan, fostered by the government (MITI), could be quite rapid. Particularly important in this regard is the close working relationship the Japanese fuel cell developers have with the country's electric power companies. This will ease the difficulties the manufacturers might encounter in the early stages of commercial transition. Over the next fifteen years the well coordinated Japanese effort probably will place that country's fuel cell manufacturers in a position comparable or perhaps superior to their U.S. counterparts barring significant increases in this country's efforts. In Japan, fuel cells using primarily imported natural gas are expected to provide a few percentage points of total generating capacity by 1995, and could provide 7-8 percent of generating capacity at the beginning of the 21st century.

The rate at which fuel cells are deployed in the United States probably will be slow at first, until confidence among potential investors is built up. The length of this transitional period is a matter of speculation. It is likely that the first commercial units will not be erected until investors are convinced these early commercial systems will operate well. Since both the small (200-400 kWe) and large (multi-megawatt) demonstration units will not be installed until the latter part of the 1980's, operating experience sufficient to justify initial commercial orders probably will not develop until the beginning of the next decade. It is likely that the proposed termination of Federal funding of phosphoric acid fuel cell development will slow this process and perhaps weaken the industry's competitive status with the Japanese; but it is not clear how serious the effect will be.

The potential market in the United States is very large. An EPRI study of the potential utility market suggests that fuel cells could provide as much as 65,000 MWe of generating capacity by 2005. At the same time, circumstances favor non-utility development too. Substantial advantages are associated with dispersed cogeneration applications under non-utility ownership. Investors, led by the gas utilities and perhaps the fuel cell manufacturers themselves, could stimulate rapid growth in non-utility applications in the 1990's.

By the mid 1990's, total experience around the country and in Japan could be sufficient to trigger rapid growth in the technology in the late 1990's. With very favorable conditions, this growth could occur even sooner. Various impediments, however, could delay extensive commercial deployment until after the close of the century. These impediments are listed below.

Equipment Cost and Performance. Current evidence suggests that it is possible to mass produce fuel cells, to sell them at acceptable prices, and to operate them without excessive problems. However, this is by no means certain. Demonstration plants are necessary to reduce the uncertainty to a level more acceptable to investors. Further research and development, aimed at incremental improvements in the equipment, would increase the possibility that cost and performance will fall within the necessary ranges in the 1990's.

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Perhaps the most important impediment facing the fuel cell is the lack of an initial market sufficient to justify mass-production. Without a sizeable initial market, only small numbers of relatively expensive fuel cells can be manufactured. These must be sold at high prices--thereby inhibiting demand--or the manufacturer must, in the short term, operate at a loss. The time it takes to overcome this problem will, perhaps more than any other factor, determine the rate of commercial application of fuel cells in the 1990's.

Technology Demonstration. The successful demonstration of both small and large fuel cells will be of critical importance to stimulating investment in the technology. Demonstration units will be needed to encourage the initial round of orders.

Utility energy and capacity credits, and interconnection requirements. As mentioned above, a major market for fuel cells lies outside the electric utilities. Like other grid-connected, non-utility applications initiated under PURPA, low energy credits, low capacity payments, and stringent interconnection requirements discourage deployment by non-utilities. Even where the possibility exists that credits could drop during the lifetime of a project, investment is discouraged. Also, any difficulties (such as delays) encountered in seeking to obtain favorable credits or interconnection requirements discourages non-utility deployment.

Licensing and Permitting Delays. In the long term, licensing and permitting delays are likely to be minimized by virtue of the technology's relatively low environmental impacts. However, other circumstances might lengthen delays. The technology will in many instances be installed in areas where power plants have not been traditionally sited and in highly populated areas where safety considerations are likely to be heavily emphasized. Moreover, the technology is new and regulatory officials are not well acquainted with it. The 4.5 MWe facility which was installed in New York was the subject of many unexpected delays; similar problems could develop with future plants.

Table 1 .—Cost and Performance of Fuel Cell Powerplants[1]

May 1985 technology status	Large	Small
Level of technology development[2]:	Demonstration units planned	Demonstration units operating[3]
Installed capacity:	none	1.5 MWe[4]
Reference system: general characteristics		
Reference year: 1995		
Deployment level scenario:[5]		
High	800-1,200 MWe	
Medium	400-600 MWe	
Low	40 MWe	
Plant size (number of units x unit size):[6]		
Gross	1 x 11.5 MWe	2 x 200 kWe
Net	1 x 11.0 MWe	2 x 200 kWe
Lead-time[7]	3-5 years	2 years
Land required	0.5 acres[8]	480-600 sq. ft[9]
Water required[10, 11]	negligible	
Reference system: performance parameters		
Operating availability[12]	80-90 percent	
Duty cycle	Variable	Variable
Plant lifetime[13]	30 years	20 years
Plant efficiency[14]	40-44 percent[15]	36-40 percent[16]
Reference system: costs		
Capital costs:	$700-$3,000/kWe[17]	$950-$3,000[18]
O&M costs (mills/kWh):[19]		
Base/Cogen (75 percent c.f.)	4.2-11.5	4.2-11.5
Intermediate (40 percent c.f.)	4.2-11.3	4.2-11.3
Peaking (10 percent c.f.)	4.3-10.7	4.3-10.7
Fuel costs (mills/kWh)[20]	27-30	30-33

[1]Only phosphoric-acid fuel cells are considered.

[2]In 1983, no commercial-scale demonstration units were operating in the United States. In 1984 the first of a series of about fifty 40-kWe units were operating in the United States, and a 4.5 MWe facility was operating in Japan. Further demonstration units are planned for the next five years, in a variety of sizes, both in Japan and in the United States.

[3]These units are 40 kWe, and are substantially different in design from the larger units (with capacities of several hundred kWe) expected to be commercially deployed in the 1990s.

[4]This consists of 36 units rated at 40 kWe each.

[5]The low estimate assumes that approximately fifty 40 kWe (net) units, two 11-MWe units, and two 7.5-MWe powerplants will have been installed by 1995. All would be demonstration units, some of which will cease operation before 1995. The low scenario assumes that no commercial units will be operating in 1995.

The medium scenario assumes the following: 1) The bulk of initial orders will be for large fuel cell powerplants rather than small ones. 2) Investors will not initiate commercial fuel-cell projects until they have seen demonstration units operating for a year. 3) Large commercial demonstration units will go into service in 1988-89, and investors will initiate projects no sooner than 1989-90. 4) Demonstration and commercial projects will have lead-times of 3 years; the commercial projects therefore would not yield operating generating capacity until 1992-93. 5) Beginning in 1992-93, an average of 200 MWe of fuel cell powerplants will be placed in operation each year through 1995. This deployment level is considered by industry sources to be the minimum level which allows the economic production of fuel cells in one manufacturing facility. This is equivalent to the startup of about eighteen 11 MWe plants each year.

This results in a deployment scenario of 400 to 600 MWe (absorbing all of the fuel cells produced in 2 to 3 years from a single manufacturing facility). This is equivalent to between thirty-six and fifty-five 11 MW units, though in actuality the installations would vary in size.

The high scenario is based on assumptions (1) through (4) above. Assumption (5) however is changed to an average deployment level of 400 MWe annually from 1992-93 through 1995—double the deployment levels assumed in the medium scenario. This results in a deployment level in 1995 of 800 to 1,200 MWe. This deployment level could be met by expanding the fuel-cell output of a single manufacturing plant, or by operating more than one manufacturing plant. Under this scenario, the equivalent of thirty-six 11 MWe plants would be started up each year, starting in 1992 or 1993, a total of 73 to 109 such plants would be operating by mid-1995 under this scenario.

[6]The small fuel cell installations deployed in the 1990s likely will be built around two or more stacks each capable of delivering 200 kWe (net) AC. It is assumed that two stacks would be used in the reference plant, but several more might be deployed at any one site. It is assumed that the large fuel cell installations in the 1990s will be built around stacks each capable of generating 250 to 700 kWe (DC). Installation capacity probably would range from several megawatts and up. The installation assumed here would consist of approximately 16 stacks each capable of generating 675 kWe (DC). While larger or somewhat smaller installations are likely to be built and operated, their cost and performance should roughly coincide with that of the 11 MWe plants.

[7]The lower estimate for the large fuel cell installation is based on discussions at OTA Workshop on Fuel Cells, Washington, DC, June 6, 1984. The upper estimate for the large plant is based on estimates made by California Energy Commission, *Technical Assessment Manual*, vol. I, Edition III (Sacramento, CA: CEC, 1984), P300-84-013, and by OTA staff. The greatest uncertainty in the range results primarily from uncertainty regarding regulatory delays. Many of the fuel cell installations are likely to be deployed in areas where little previous powerplant development has occurred, and where population densities increase the possibilities for regulatory conflicts. The potential for regulatory problems was exemplified by a 4.5 MWe demonstration unit which was built (but never operated) in New York City. Numerous unanticipated regulatory delays were encountered, and prevented the expeditious completion of the plant; approval of the project by New York City's fire department took 3 years.

The estimate for the small fuel cell installation is based on discussions at OTA Workshop on Fuel Cells, op. cit., 1984. The extremely small size of the plant suggests that regulatory delays would be considerably less problematic than would be the case with larger plants. Some within the industry believe that lead-times could be as short as several months; see R.A. Thompson, Manager, Business Planning, United Technologies Corp., Fuel Cell Operations, personal correspondence with OTA staff, Feb. 15, 1985.

[8]Burns & McDonnell Engineering Co., *System Planner's Guide for Evaluating Phosphoric Acid Fuel Cell Power Plants* (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI EM-3512. See also comments of Thompson, op. cit., 1984.

[9]OTA estimate based on two modules, each measuring 20 x 8 feet. This is the size of module suggested by Richard R. Woods, Jr., Manager, Fuel Cells, Gas Research Institute, in personal correspondence with OTA staff, Feb. 4, 1985.

[10]United Technologies Corp., *Specification for Dispersed Fuel Cell Generator*, Interim Report (Palo Alto, CA: Electric Power Research Institute, 1981), EPRI EM-2123, Project 1777-1.

[11]United Technologies Corp., Power Systems Division, *Onsite 40-kilowatt Fuel Cell Power Plant Model Specification*, prepared for U.S. Department of Energy and the Gas Research Institute (South Windsor, CT: United Technologies, September 1979), FCS-1460.

[12]This is based on Fuel Cell Users Group, System Planning Subcommittee, Ad Hoc Reliability Task Force, *Report on Fuel Cell Reliability Assessment* (Washington, DC: Fuel Cell Users Group, March 1983). The report recommended use of an 85 percent availability factor in system planning studies for large fuel cell powerplant installations. It however stated that availability could range between 80 and 88 percent, depending on assumptions made about component redundancy and about the availability of spare parts. It is asserted that the operating availabilities of small fuel cell powerplants will fall within the same range as that of the larger fuel cells, as no comparable stacks are available on the operating availabilities of the small plants.

[13]This refers to the plant lifetime. Cell stacks themselves are assumed to have lifetimes of 40,000 hours when running at full capacity.

[14]This is the operating efficiency at which electricity is produced when the plant is operated at its full rated capacity. In cogeneration applications, where useful heat will be produced along with electric power, the total energy efficiency (which includes all useful energy outputs, thermal and electric) would be much higher. The cogeneration efficiency could be as high as 85 percent.

[15]Based on higher heating value of fuel. This range is consistent with estimates made in numerous sources, including: 1) United Technologies Corp., *Specification for Dispersed Fuel Cell Generator*, Interim Report (Palo Alto, CA: Electric Power Research Institute, 1981), EPRI EM-2123, Project 1777-1. 2) Mike Ringer, California Energy Commission, *Relative Cost of Electricity Production* (Sacramento, CA: CEC, December 1983). 3) "Utilities Show Interest in Large Fuel Cell Installations for Late '80s," *Electric Light and Power*, vol. 62, No. 6, June 34, p. 53. 4) Irwin Stambler, "Fuel Cell Outlook Brightens as Technical Obstacles Fall," *Research & Development*, December 84, pp. 50-53. 5) Battelle, Columbus Division, *Final Report on Alternative Generation Technologies*, vols. I and II (Columbus, OH: Battelle, 1983). 6) Thompson, op. cit., 1985.

[16]Based on higher heating value of fuel. From: 1) J.W. Stanwood and G.P. Morten and R.M. Smith, United Technologies Corp., *Follow-On 40-kWe Field Test Support*, Annual Report, prepared for Gas Research Institute (Chicago, IL: Gas Research Institute, 1984), FCR-6494, GRI-84/0131. 2) Woods, op. cit., Feb. 4, 1985.

[17]Estimates do not include cell replacement costs. The lower end of the range assumes a mature technology and mass production; the high end of the range represents the estimated cost of the commercial demonstration units expected to be installed and operated in the late 1980s. Within this range fall the estimates cited in the following: 1) The participants in an OTA Workshop on Fuel Cells, op. cit., 1984. 2) Ringer, op. cit., 1983. 3) California Energy Commission, op. cit., 1984. 4) I.R. Straughn, Southern California Edison Co., "R & D Input to the Fall 1984 Generation Resource Plan," unpublished memorandum, August 1984. 5) Lee Catalano, "Can Fuel Cells Survive the Free Market in the 1990's?" *Power*, vol. 128, No. 2, February 1984, pp. 61-63. 6) Burns & McDonnell Engineering Co., *System Planner's Guide for Evaluating Phosphoric Acid Fuel Cell Power Plants* (Palo Alto, CA: Electric Power Research Institute, 1984), EPRI EM-3512. 7) Battelle, op. cit., 1983. 8) J.R. Lance et al., Westinghouse Electric Corp., "Economics and Performance of Utility Fuel Cell Power Plants," *Advanced Energy Systems—Their Role in Our Future*, Proceedings of 19th Intersociety Energy Conversion Engineering Conference, Aug. 19-24, 1984, San Francisco, CA (U.S. American Nuclear Society, 1984), paper 849133, pp. 821-829.

Where a single "expected" value is used in this report, a value of $1,430/kWe is used.

[18]The estimates do not include cell replacement costs. The lower end of the range assumes a mature technology and mass production; the high end of the range represents the estimated cost of the first commercial cogeneration units. Within this range fall the estimates cited in the following: 1) Richard Woods, Gas Research Institute, as quoted in Ernest Rua, "Fuel Cells Spark Utilities Interest," *High Technology*, vol. 4, No. 12, December 1984, pp. 52-57. 2) Catalano, op. cit., 1984. 3) OTA Workshop on Fuel Cells, op. cit., 1984. 4) Thompson, op. cit., 1985.

As an expected value for capital costs, OTA uses in its analysis a value of $2,240 (1983 $). This is based on an estimate made by the Gas Research Institute (GRI) of the cost of a 200 kWe cogeneration module; see Stephen D. Barr, GRI, *Gas-Fueled Cogeneration—GRI's Current R&D Program*, unpublished monograph (Washington, DC: GRI, n.d.). The GRI estimate referred to the expected costs during the period of early market entry, with low quantity fuel cell production levels.

Table 2.—Federal Program Funds in Support of Developing Technologies (millions of dollars)

Technology	Year											
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986 (requested)
Wind	7.9	14.4	27.6	35.5	59.6	63.4	54.6	34.4	31.4	26.5	29.1	20.8
Photovoltaics	5.2	21.6	59.7	76.2	104.0	150.0	152.0	74.0	58.0	50.4	57.0	44.8
Solar thermal	13.2	20.6	79.1	114.7	109.3	135.0	120.0	56.0	50.0	43.9	35.5	28.4
Geothermal	28.0	78.3	76.7	132.9	188.4	171.0	156.3	86.6	73.6	30.5	32.1	12.0
AFBC	2.0[a]	7.0	21.2	24.5	23.6	25.9	11.4	0.3	4.9	1.4	18.7	17.3
Surface coal gasification[b] (includes IGCC)	116.3	117.7	143.2	208.2	122.4	123.3	70.0	54.2	39.0	36.5	32.0	15.0
Fuel cells[c]	n/a	3.0	17.8	33.0	41.0	26.0	32.0	34.5	29.9	42.3	40.8	9.3
Batteries[d]	2.9	6.8	9.7	11.2	15.3	20.3	13.9	12.9	12.8	12.8	8.4	6.3
CAES	0.0	0.6	1.2	4.5	4.5	3.2	2.1	2.0	0.0	0.0	0.0	0.0
Total	175.5	270.0	436.2	640.7	668.1	718.1	612.3	354.9	299.6	244.3	253.6	153.9

[a]OTA estimate.
[b]Does not include support from the Synthetic Fuels Corp.
[c]Includes funding for all fuel cells R&D and is not restricted to phosphoric acid fuel cells.
[d]The funding levels listed are the estimated levels of support for all stationary batteries, including but not restricted to lead-acid batteries and zinc-chloride batteries. The estimates assume that roughly 50 percent of the funding for DOE's Electrochemical Program is applicable to stationary batteries.

SOURCE: U.S. Department of Energy, *Congressional Budget Request: FY 1986* (Washington, DC: U.S. Government Printing Office, 1985) and the corresponding documents for previous years.

Senator EVANS. Thank you, very much.
Next is Fred Sissine. Please proceed.

STATEMENT OF FRED SISSINE, ANALYST IN SCIENCE AND TECHNOLOGY, CONGRESSIONAL RESEARCH SERVICE

Mr. SISSINE. Thank you, Senator Evans. I wish to thank the Committee for the opportunity to participate in this hearing. I have prepared a CRS report on the subject of fuel cell integration with wind and solar-electric facilities, and would like to ask that it be inserted in the record when it becomes available soon.

Senator EVANS. We will, indeed.

Mr. SISSINE. This morning I will focus my testimony on the technical background concerning the potential for integrating fuel cell technology with renewable power technologies. Some aspects of the integration concept are covered in Senate Bill 1686 and 1687.

Changing winds and sunshine levels can cause the power output of wind and solar-electrical technologies to vary dramatically from minute-to-minute and from day-to-day. This probably is a major constraint on the number of applications and the energy contribution from these renewable power technologies. It has led to several schemes for smoothing the variable outputs of wind and solar power devices. However, these strategies for leveling outputs have significant technical and economic limitations.

Fuel cells may offer a more economically and technically viable solution for the longstanding problem of renewable power output variability. a fuel cell's power output can be adjusted in less than one-hundredth of a second in response to rapidly changing demands.

This feature is known as load-following capability. It has been demonstrated technically for commercial building loads in a 2-year field test with 10 natural gas-fired fuel cell units, each of which has a 40-kilowatt capacity.

This test was performed by gas utilities under a cost-shared arrangement between the Department of Energy and the Gas Research Institute.

An integrated system would achieve constant power production by using the fuel cell, fueled by natural gas, to follow the wind or solar power output. Assuming for the purposes of operating efficiency that the rated power capacity of the fuel cell should be about 33 percent greater than that of the associated renewable energy device, then an integrated wind-fuel cell system, for example, with a total capacity of 40 kilowatts would require a 30 kilowatt wind machine and a 40 kilowatt fuel cell. At peak wind production, 30 kilowatts, the fuel cell would be supplying 10 kilowatts.

As wind production falls off, the fuel cell's output is increased to maintain constant system output. If the wind machine shuts off altogether, the fuel cell would operate at its full capacity. The proportion of fuel cell capacity required to ensure firm output might be reduced by adding a solar-electric device or battery storage to the system, but this would also increase the system's installation costs.

However, many questions about the composition and the sizing of components which would yield the most technically efficient and

cost-effective system remain to be resolved by research and demonstration, and by composition of the system, I am talking about whether you would include wind with fuel cells, wind with solar and with fuel cells, or perhaps wind with fuel cells with battery storage—some combination of that type.

The potential for solving the output variability problem of wind and solar power facilities by integrating them with fuel cells is beginning to receive international attention. In June 1985, the idea was put forth by Mr. Bruce Birnbaum at an international workshop on fuel cells held, sponsored by UNESCO, and held in Ravello, Italy. Also, in August 1985, the concept was described in a paper presented by Dr. Saifur Rahman, who we heard from earlier, to the International Conference on Solar and Wind Energy Applications held in Bejing, China.

Dr. Rahman's research in this area has continued, but has been limited primarily to simulation studies of relatively small standalone systems. The integration idea could also be applied to the development of larger scale systems connected to electric utility grids.

If integrated systems can solve the output variability problem, their development might have several positive impacts on the use of fuel cells and renewable power technologies. First, integration could reduce fuel cell operating by using wind and solar-generated electricity to displace fuel purchases, primarily natural gas. This could be important for applications in isolated and rural areas where conventional fuels are costly or unavailable.

Second, integration retrofits, depending on costs, could improve the revenue potential of windfarms and grid-connected solar equipment by increasing their eligibility for capacity credit payments under PURPA. These payments are required to be made by utilities to installations which can guarantee production during peak demand periods. Wind and solar outputs are often correlated with peak demand, but the inability to provide constant power disqualifies them from these payments.

Perhaps most important, again depending on costs and competition, integration could expand the projected markets for both fuel cells and renewable power equipment. Because the U.S. currently holds a technical advantage in fuel cell technology, U.S. industry could be the first to manufacture integrated systems.

With expanding markets, increased production volumes would likely reduce unit costs for both types of technology. Lower unit costs could further expand the markets and improve the competitiveness of U.S. equipment in domestic and foreign markets. These markets are likely to be influenced by declining energy prices, which could hurt the market outlook for renewable power technologies. However, reduced gas prices could increase the attractiveness of integrated systems because the fuel cell component would use natural gas.

The two bills present before the committee, S. 1686 and S.1687, require the Federal Government to pursue research with integrated systems and to facilitate regulatory review of fuel cells in general. The provisions in S. 1687, which named PURPA to make fuel cells eligible for energy and capacity credits could, depending on system costs, enhance the market for integrated systems.

If a commercial market develops, environmental guidelines for the safety aspects of fuel storage accompanying fuel cells would be needed. S. 1687 provisions address that prospective need.

In considering these bills, the committee may also wish to consider two additional aspects which the bills do not currently address. First, S. 1687 directs the Commerce Department to assess foreign markets for integrated systems. This provision could be expanded to include a companion assessment of domestic and foreign markets for fuel cells alone. This additional information could help the committee compare the market for integrated systems with the individual markets for fuel cells and renewable power technologies. It could also be used to help establish the extent to which integrated systems might expand either of these other markets.

Second, a provision in S. 1686 directs DOE to study integrated systems for rural and isolated areas; here the committee might consider including research on grid-connected applications. There are three reasons for this. First, although research has been performed on connecting fuel cells alone with utility grids, integrated systems would have different power characteristics which may warrant further investigation. Second, the technical demands for a grid-connected, integrated system differ from those for a stand-alone system. Third, the market for grid-connected integrated systems is likely to be much larger than the stand alone market, especially in the near future.

Integrated systems, if they become cost-competitive, could act as a buffer for utilities that experience rapid or unexpected growth in demands for electric power; these systems could be added to utility capacity quickly and in increments which follow the growth rate closely. If this situation should develop, a larger market for manufacturers of fuel cell and renewable power technologies would open up, possibly quickly. If it is considered important that domestic manufacturers are to be in a position to take advantage of this larger market, Federal actions to help accelerate the development and demonstration of integrated systems may be necessary.

With current trends, the market for integrated systems would be largely won by foreign manufacturers who have been capturing a growing fraction of both foreign and domestic markets for renewable power technologies.

Thank you.

[The prepared statement of Mr. Sissine follows:]

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UNITED STATES SENATE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

HEARING ON

SENATE BILLS S. 1686, THE "RENEWABLE ENERGY/FUEL CELL SYSTEMS INTEGRATION ACT OF 1985," AND S. 1687, THE "FUEL CELLS ENERGY UTILIZATION ACT OF 1985" AND OTHER MATTERS RELATED TO FUEL CELLS

FEBRUARY 24, 1986

STATEMENT OF FRED SISSINE

ANALYST IN SCIENCE AND TECHNOLOGY

CONGRESSIONAL RESEARCH SERVICE

LIBRARY OF CONGRESS

I wish to thank the Committee for the opportunity to participate in this hearing. I have prepared a CRS report on the subject of fuel cell integration with wind and solar-electric facilities, and would like to ask that it be inserted in the record. This morning, I will focus my testimony on the technical background concerning the potential for integrating fuel cell technology with renewable power technologies. Some aspects of the integration concept are covered in S. 1686 and S. 1687.

Changing winds and sunshine levels can cause the power output of wind and solar-electric technologies to vary dramatically from minute-to-minute and from day-to-day. This problem is a major constraint on the number of applications and the energy contribution from these renewable power technologies. It has led to several schemes for smoothing the variable outputs of wind and solar power devices. However, these strategies for leveling outputs have significant technical and economic limitations.

Fuel cells may offer a more economically and technically viable solution for the long-standing problem of renewable power output variability. A fuel cell's power output can be adjusted in less than one-hundredth of a second in response to rapidly changing demands. This feature is known as load-following capability. It has been demonstrated technically for commercial building loads in a two-year field test with 10 natural gas-fired fuel cell units, each of which has a 40-kilowatt capacity. This test was performed by gas utilities under a cost-shared arrangement between the Department of Energy (DOE) and the Gas Research Institute (GRI).

An integrated system would achieve constant power production by using the fuel cell, fueled by natural gas, to follow the wind or solar power output. Assuming for the purposes of operating efficiency that the rated power capacity of the fuel cell should be about 33 percent greater than that

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The potential for solving the output variability problem of wind and solar power facilities by integrating them with fuel cells is beginning to receive international attention. In June 1985, the idea was put forth by Mr. Bruce Birnbaum at an international workshop on fuel cells held in Ravello, Italy. Also, in August 1985, the concept was described in a paper presented by Dr. Saifur Rahman, of Virginia Polytechnic University, to the International Conference on Solar and Wind Energy Applications held in Bejing, China. Dr. Rahman's research in this area has continued, but has been limited primarily to simulation studies of relatively small stand-alone systems. The integration idea could also be applied to the development of larger scale systems connected to electric utility grids.

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take advantage of this larger market, Federal actions to help accelerate the development and demonstration of integrated systems may be necessary. With current trends, the market for integrated systems would be largely won by foreign manufacturers who have been capturing a growing fraction of both foreign and domestic markets for renewable power technologies.

Senator EVANS. Thank you.
Richard Alkire.

STATEMENT OF DR. RICHARD C. ALKIRE, PROFESSOR OF CHEMICAL ENGINEERING, UNIVERSITY OF ILLINOIS

Dr. ALKIRE. Thank you. If I may comment informally, I used to be a pitcher, so I am used to batting last.

Currently, however, I am a professor of chemical engineering at the University of Illinois, and currently serve as president of the Electrochemical Society, a society in which many of the scientific and technological aspects of fuel cell systems is exposed. I have chaired two committees for the National Research Council, one on fuel cell material technologies in vehicle propulsion, and another currently on new horizons on electrochemical science and technology.

I would like to comment—I would like to ask that my statement be entered in the record.

Senator EVANS. Your statement will be entered in full in the record.

Dr. ALKIRE. I would like to comment just informally. I would like to comment about the state of science in electrochemistry, in the sense that there has been a sudden jump in capabilities in that science. And so the message is briefly, that there is a sudden increased capability of scientific and technical knowledge in electrochemistry including fuel cells and other areas; that the combined social and economic impact of electrochemistry is much broader than just fuel cell systems.

The unique feature then of this sudden capability that we find is that it impacts a very large dollar volume in systems that are very highly energy intensive. The fuel cell plays an important role in the advancement of this science and it can contribute to the science and it can also draw from developments elsewhere.

In order to benefit from this development and improved focus on the institutional facts would be helpful.

I would like to take one example in particular, although I could have taken several, and take a minute and pursue it somewhat to its molecular limits. The example I will choose is the actual reaction that occurs deep within the heart of a fuel cell system.

You have heard from several people that this reaction is adversely influenced by poisons in the fuel. It does influence the cost of the electrode, when the electrode is expensive. It influences the efficiency of the device and produces unwanted heat, and it can also be adversely affected by the lifetime, that is by molecular events which ruin the ability of the surface to cause a reaction to occur.

This reaction and the reaction site associated with the reaction measures on the order of 100 Hangstrom units. That is roughly 10 billion times smaller than the actual fuel cells system.

It has only been with in the last 5 or so years that we have gained the ability to study molecular events in electrochemical system on that scale. The particular achievements that have been made are in developing new systems for determining the specific chemicals which participate in the reaction, to study the reaction on short time scales which are typical of the varied time scales

where these processes occur, and to resolve the spacial characterization of the interface on the order of 100 Hangstrom level.

The new techniques for these capabilities have led therefore to a vigorous growth in theoretical understanding of those phenomena and have in particular developed a number of experimental leads for both oxygen and methane reactions.

If we start from fuel cells and identify this 100 or so Hangstrom scale phenomenon, we come to the same conclusion as we if we had started from any other electrochemical processes. For example, we could have started from the oxygen reaction that occurs during corrosion, or the oxygen reaction that occurs during the production of many metals or batteries, where the behavior of materials or in fact life processes themselves, where oxygen is used in the body for reaction, communication and energy conservation.

The knowledge that we gain by the study of oxygen and methane reactions in fuel cells can therefore feed a wide range of other technologies that depend virtually on similar electrochemical events. The combined dollar volume, that is, value added of these technologies, including corrosion, approaches $200 billion annually in the United States. The combined consumption of electricity in the United States of the electrolitic technologies is 7 percent.

These are very large numbers and I feel that the fuel cell area can contribute significantly to the advancement of other electrochemical technologies.

In summary, I think that I wish to emphasize that the electrochemical field in science and technology is undergoing a renaissance. The unique feature of that renaissance is the enormous dollar volume and energy volume of the technologies which it impacts. Fuel cells can contribute to that renaissance and can also draw advantageously from advances elsewhere in the field.

Thank you, very much.

[The prepared statement of Dr. Alkire follows:]

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STATEMENT OF

RICHARD C. ALKIRE
PROFESSOR OF CHEMICAL ENGINEERING

UNITED STATES SENATE
COMMITTEE ON ENERGY AND RESOURCE
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

FEBRUARY 24, 1986

INTRODUCTION

Fuel cell systems produce electricity directly from the electrochemical combustion of a fuel. Such systems by-pass the conversion of fuel into heat and mechanical energy, and thus achieve theoretical efficiencies which are significantly higher than conventional methods of power generation. The increased efficiency is relatively independent of power-plant size so that standardized modular units can be added based on relatively short-range power needs and capital availability.

The heart of a fuel cell system is the electrochemical device which changes the chemical energy of the fuel and oxidant into electrical energy. In a typical arrangement, fuel such as methane gas enters a chamber and undergoes electrochemical reaction at an electrode. Oxygen, usually as air, enters a second chamber and is electrochemically consumed by reaction at a second electrode. By these reactions, electricity is delivered to an outer circuit in order to perform useful work. Within the device, the two electrodes are separated by an electrolyte.

The fundamental phenomena which occur within a fuel cell are similar to those which occur in many other electrochemical devices and processes. Such phenomena have been harnessed to provide unique materials which are essential to our civilization. Aluminum for buildings and subsonic aircraft, and titanium for supersonic aircraft and tanks, for example, are made exclusively by electrolytic processes. Pacemaker batteries sufficient for a lifetime are today a reality. Electrochemical phenomena are also at the root of corrosion, which influences safety and reliability of automobiles, bridges, nuclear power plants, and microelectronic devices. Electrochemical phenomena can be used for synthesis of biomaterials, and are also essential to the organization and dynamic behavior of living matter such as cells, nerves and muscles.

The value-added economic impact of these technologies which are directly associated with electrochemical phenomena is approximately $200 billion annually in the United States. These industries presently consume about 7% of the electricity generated in the U.S. Applications include the energy, environment, industry, health, transportation, and defense interests of our nation. As important as these benefits are, the technological understanding of the basic phenomena which affect reliability, efficiency, and useful life, is virtually in its infancy. (Fig. 1)

BACKGROUND

Electrochemical technology emerged in the 19th century in answer to societal demands for new chemicals, materials, and energy

forms. Aluminum, refined copper and zinc, batteries, electrodeposition of metal films, chlorine, along with corrosion protection, are representative of such mature technologies. These industries grew, in their early years, in the absence of rudimentary scientific and engineering principles. Their early development was characterized by slow evolutionary change based on trial-and-error experience and intuition. Such a characterization of the field, however, has been completely reversed by recent events.

The scientific and industrial creativity required for economic efficiency has turned toward fundamental understanding of physical and chemical phenomena in the key processes of virtually every important global electrochemical industry. The invention of new materials and of improved engineering methods has revolutionized the electrolytic process industries. For example, over 90% of U.S. chlorine capacity now uses coated titanium electrodes which were a laboratory curiosity only two decades ago. Such growth has also contributed significantly to "new frontier" industries and products, for example in advanced materials, microelectronics, sensors, bioelectrochemistry, and health care systems. (Fig. 2)

In all of these old and new industries, the key scientific cornerstone is the understanding of electrochemical phenomena which control the existence, movement, and reaction of chemical species in the bulk volume and at interfaces between electrodes and electrolytes. The range of such materials is truly staggering, and includes ionic, electronic, semiconductor, photonic, and dielectric materials.

WHAT IS NEW?

A virtual renaissance has occurred in the field of electrochemistry during the 1980's. These advances took place owing to new-found abilities to create precisely characterized system for fundamental study, to monitor their behavior at previously unattainable levels of sensitivity, and to predict behavior with new theories and super computer facilities. These capabilities are creating extraordinary opportunities, both in electrochemical science and in the transfer of that science into new products and processes. (Fig. 3)

For example, the electrochemical field is now capable of making significant advances in the microscopic description of the precise chemical species, in the atomic structure of the reaction sites on electrodes, and in the molecular events that determine the rates and products of electrode processes. New techniques now permit investigation at timescales, molecular specificity, and spatial resolution which are orders of magnitude superior by comparison with only a decade ago. These accomplishments will trigger advances which are fully comparable to those brought about in astronomy by the invention of the telescope.

The unique feature of these new capabilities is that they are intimately coupled to both old and new technologies which are widespread and which possess high dollar and energy value.

The electrochemical field has thus suddenly become poised to make major advances. Significant changes in entire industries could take place as new electrochemical materials, devices, and processes become commercially realizable. The nation achieving these objectives earliest will be in a strong technological position at the turn of the century.

RESEARCH OPPORTUNITIES FOR FUEL CELLS

Fuel cells have new opportunities for advancement unparalleled in recent history. Just as metallurgy influenced the industrial revolution, so fuel cells for stationary power and vehicular propulsion offer unique properties that could well restructure energy use patterns in our society in the 21st century.

A fundamental understanding of the materials, processes, and reactions of fuel cell systems is essential to accelerate technological process of that magnitude.

There are currently five major types of fuel cells, each having different internal materials such as electrodes and electrolytes, and each offering different ranges of performance and operating conditions. The following examples illustrate opportunities where new techniques clearly hold rich promise:

Reaction of Oxygen and Methane at the two electrodes in the fuel cell is invariably sluggish except on all but a few expensive materials. Fundamental knowledge of the precise molecular events which occur during reaction must be gained in order to invent new, low-cost catalyst materials, especially in phosphoric acid fuel cells. Incorporation of this knowledge in the design of practical electrode structures is necessary. Vastly superior experimental and theoretical techniques are now available for such studies.

Polymer-Type Electrolytes can be better understood in order to improve performance, and to extend the useful range of operating conditions of solid polymer fuel cells.

Ceramic Electrolytes can be improved by better understanding of atomic-scale defects which are responsible for the unique properties that make these materials useful in solid oxide fuel cells.

Theoretical Models which closely mimic the behavior of fuel cells systems can now be developed with new, efficient, computational methods and the advent of super computers. Such models will contribute to understanding the complex phenomena that limit performance and lifetime, and to developing engineering strategies for rapid, cost-effective improvement of overall systems.

The identification and prioritization of these and other fuel cell research opportunities has been vigorously pursued during the past three years. These efforts should contribute to rapid identification and exploration of key limitations.

SPIN-OFF ADVANTAGES

It is by now recognized that many electrolytic technologies share a common base of fundamental knowledge and research techniques. Therefore, exchange of understanding between different but related technologies may be regarded as a valuable spin-off advantage. Based on the research opportunities listed above, the following examples illustrate such linkages to other electrochemical processes:

Improved Oxygen Reactivity is also recognized as a critical need for better mineral processing (zinc), chemical synthesis (chlorine), batteries (metal-air), and other (corrosion) electrolytic technologies. Also, the fundamental nature of many oxygen catalysts closely mimics the behavior of biologically active molecules. Improved understanding may therefore unlock secrets needed for advanced biotechnology and health care applications.

Improved Methane Reactivity is closely related to the electrochemical production of specialty organic chemicals, drugs, and other high value-added compounds.

Solid Polymer Electrolytes transport chemicals through their inner molecular structure in a manner which is related to the membranes which surround living cells, nerves, and muscles. Better understanding may also lead to improved sensors for health care, and to macromolecular electronic devices which respond directly to living systems in which these devices are implanted.

Ceramic Electrolytes are closely related to other high-technology ceramic materials, solid state sensors, and advanced batteries. Recent unexpected discoveries also include opto-electronic devices, and new laser and phosphor hosts.

These examples are intended to illustrate that advances in fuel cell research may also contribute to a network of fields which share common fundamental principles.

WHAT IS NEEDED?

In many respects, electrochemistry is a centuries-old technology but only a decade-old science. It has only recently been perceived that electrochemical phenomena underpin a vast range of economically significant technologies. The field is multi-disciplinary, and draws from chemistry, physics, biology, materials, and various engineering disciplines. Applications where focused multidisciplinary research would exert a highly visible impact include fuel cells, corrosion, microelectronic devices and sensors, advanced materials processing, and health care. (Fig. 4)

Electrochemistry, including corrosion, has yet, however, to find a home within the federal funding structure, as well as within the educational framework of the component disciplines.

The remarkable diversity of the electrochemical field gives it a strategic value because it is difficult to master, both at home as well as by foreign competitors. A valuable asset of the U.S. is its historically strong electrochemical research position. However, foreign countries have very aggresively used U.S. research results to develop new products which are subsequently sold in the U.S. The U.S. must therefore enhance its efforts to maintain a strong position at the leading edge of electrochemical research, but must be much more effective in transforming research results into new and improved products.

SUMMARY

1. The field of electrochemical science and technology is undergoing a major renaissance.

2. Fuel cell research can benefit significantly from recent advances throughout the electrochemical field and, in turn, can spur related fields to new heights.

3. The recent breakthrough in electrochemical science and technology has not yet been recognized by focused federal programs of support.

FIGURE 1

SUMMARY

a. Major renaissance is occurring in electrochemical science and technology.

b. Fuel Cell R & D can benefit from, and contribute to, action elsewhere.

c. Institutional focus on electrochemistry and corrosion would sustain growth.

FIGURE 2

BACKGROUND

a. Fuel cells are electrochemical devices.

b. Key limitations impact other electrochemical devices and processes.

FIGURE 3

WHAT IS NEW ?

a. New ideas in electrochemical science and engineering.

b. Unique economic impact.

c. New market growth opportunities.

FIGURE 4

NEEDS

a. Multidisciplinary emphasis.

b. Federal and academic focus.

c. Technology transfer.

Senator EVANS. Thank you. Dr. Blair, from your assessment in the work that you are doing, ranking the various kinds of energy research, and there are plenty of them that are characterized by separate lines on the Department of Energy's budget, where would you range fuel cell and associated research as compared with other energy alternatives?

Dr. BLAIR. You mean with respect to the horizon of commercialization, or——

Senator EVANS. Yes; the potential for success. Of course, in all research, you are still groping for success, but if we have a limited amount of resource, where should we put it?

Dr. BLAIR. Well, certainly if the horizon is the 1990's, and in many respects, that was the focus of our particular assessment, fuel cells rank very high on the list. Fuel cells, along with technologies like fluidized bed combustion, and even photovoltaics, rank fairly high on the list of those that are likely to achieve substantial deployment in the 1990's.

Senator EVANS. You mentioned the risk of uncertainty, which we talked about earlier today, and the fact that utilities are not only extremely reluctant, but virtually are rejecting any investment in major central plants simply because of the timeframe for construction and the uncertainty of electrical load forecasts. In your view, is that going to lead us inevitably to a system wherein the unitization or incremental nature of electric power production is going to rise in importance?

Dr. BLAIR. Well, you give me the opportunity to bring up my flood insurance metaphor, where utilities faced with highly uncertain load growth are, of course, as you mentioned very reluctant to commit to traditional large, long lead time technologies, so that the policy environment seems to be sort of like living in a flood plain where there are three options: We can wait for the big dam up the river to be built, or rely on continued commitments to large, long lead time plants and have faith that they can be built in time if needed, or perhaps take steps to make it easier for those plants to be built.

The second option is to pray that it doesn't rain. That is, that the low load growth predictions do hold true and that there isn't any pressure to get new capacity on line.

The third one is to, in effect, invest in flood insurance. That is, invest in a range of smaller scale, shorter lead time technologies that can be employed if needed. Fuel cells certainly fall into that category. The modular feature is one of the most attractive ones to utilities.

Without availability of a range of new technologies, the technology by default becomes the combustion turbine, and granted, combustion turbines can be turned into combined cycles and eventually into integrated coal gasification combined cycle units, but the scenario is still a risky one if we are going to, in effect, bet the farm on natural gas.

Senator EVANS. Dr. Alkire posed an interest concept on just the electrochemical science itself. In your view, which way do we go? Use fuel cells and fuel cell research as an entre into broader understanding of electrochemical science, or do we have better research support of the nature of electrochemical science and hope that

those results will lead us to something that will work on fuel cells? Which is the chicken in this case?

Dr. ALKIRE. Yes; if one looks historically backward, a decade or so, I would say the fuel cells have not served to be the lead in the electrochemical science of the type I have spoken—that is, academic, fundamental science. And in that sense, the young persons entering an academic career, for example, need a certain stability in funding and a certain ongoing assurance of commitment in order to pursue these types of topics. In that sense, that ongoing commitment has been formulated with respect to other electrochemical programs.

Electrochemistry tends to be a problem-oriented discipline, problem-oriented field. It does not fall into traditional disciplines. But the funding tends to arrive according to a mission, and so there is a mismatch, so to speak, in identifying funds in a way that young academics will bet their careers at the outset.

Senator EVANS. Do you propose that the Federal Government refocus its efforts, focus more support in the electrochemical science and technology field? Is that something best left to others to do?

Dr. ALKIRE. I think that the focus on the electrochemistry, including corrosion is well deserved because these are multidisciplinary problems. They are not going to be solved within any of the specific, traditional disciplines. And some focus of that type, therefore, would help to get them off the ground.

Senator EVANS. Mr. Sissine, and Dr. Blair, given the nature and the understanding of fuel cells and where we are and what the potential may be, do you think that it is legitimate or appropriate for either the Department of Transportation or the Department of Defense to use some of their resources to enhance the speed with which we move ahead on research in these fields?

Mr. SISSINE. I would assume so. I believe that the Department of Defense has done some testing already with the 40 kilowatt, one or two of the 40 kilowatt systems.

Senator EVANS. They are testing. They are not contributing with others in the more fundamental research area?

Mr. SISSINE. I just don't know much about that. I would be glad to look into it for you and submit something later, but I just haven't looked much to that.

Mr. JOHNSON. I could add something to that. In our look at marine applications, this little red book here, we did involve some people from Ft. Belvoir, the Army, who are right now doing some work on reformer technology for diesel fuel reforming for fuel cells. And the Army also has developed some very small fuel cells, phosphoric acid fuel cells for remote applications.

The problem that they ran into was that these were designed to use methanol as a fuel and methanol isn't available in the Army very much, so they are working right now on diesel oil reforming systems for the fuel cell.

Senator EVANS. Seems to me that remote applications sure fits as far as the military is concerned.

OK. DOD has just zeroed out Army's research on fuel cells. Consequently, they turned down our invitation. At least the administration is consistent. They wanted it zeroed out in all respects; stamp it out as if it never existed.

OK. We do appreciate very much your not only willingness to come and testify and your contribution, but also your extreme patience in waiting for most of the day. It is one of those things that I have come to hate, but understand; we never can predict what the schedule will be around here. Maybe that is the kind of research and development we need to carry on.

But, I am sure that the results of today's hearing will be very valuable to us. We will see what the end results will be in terms of our own recommendations on budget. Based on the testimony this morning from the Department of Energy and the administration, I am not sure it is going to make any difference anyhow, because they don't tend to spend what we appropriate. But we will see what we can do about that.

Thank you, very much.

[Whereupon, at 3:50 p.m., the hearing was adjourned.]

APPENDIXES

APPENDIX I

Responses to Additional Questions

Department of Energy
Washington, DC 20585

April 3, 1986

Honorable Pete V. Domenici
Chairman, Subcommittee on Energy
Research and Development
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

On February 24, 1986, Robert L. San Martin, Deputy Assistant Secretary for Renewable Energy, and Richard L. Harrington, Deputy Assistant Secretary for Coal Utilization, Advanced Conversion and Gasification, appeared before the Energy and Natural Resources Subcommittee on Energy Research and Development to discuss S. 1686 and S. 1687 relating to fuel cell integration and utilization.

Following that hearing, you submitted written questions for our response to supplement the record. Enclosed are the answers to those questions, which also have been sent directly to the Committee staff.

If you have any questions, please have your staff call Ingrid Nelson or Cathy Hamilton on 252-4277. They will be happy to assist.

Sincerely,

Cathy J. Hamilton for

Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosure

POST-HEARING QUESTIONS AND ANSWERS

RELATED TO THE

FEBRUARY 24, 1986 HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

Question 1: In your testimony, you have stated that "this multipronged research effort is well coordinated," and I also understand that DOE participates in "National Fuel Cells Coordinating Groups." Would you elaborate on the R&D coordination with DOD and NASA? Are there any tangible evidences that basic information are shared, and we do have a cohesive program on Fuel Cells?

Answer: Formal coordination between the DOE, DOD, and NASA takes place through two groups which meet annually. These are the Chemistry Working Group of the Interagency Power Group and the Fuel Cell Users' Group. Meetings of the latter include attendees representing manufacturers, electric and gas utilities, the Electric Power Research Institute, and the Gas Research Institute (GRI).

Informal coordination occurs and information is shared through papers presented at meetings and published in the Journal of Power Sources, the Journal of the Electrochemical Society, the proceedings of the IECEC, and similar publications. In addition, DOD, NASA, and DOE participate in fuel cell seminars and workshops providing technical presentations and discussions of R&D efforts. Other coordination takes place through personal contacts of Government personnel and researchers. Through this coordination, a program has developed which addresses the critical research needs.

The DOD is a participant in the DOE/GRI 40 kW fuel cell field test program with four test units (at Sheppard AFB, Wright-Patterson AFB, Elmendorf AFB and Fort Belvoir). The DOE/METC fuel cell project manager has provided technical assistance in the study funded by the Department of the Army and performed by Georgetown University to evaluate a coal gasification fuel cell project. Coordination with NASA sponsored fuel cell research and development is aided by the fact

that the NASA's Lewis Research Center has been the lead center for phosphoric acid fuel cells (PAFC) (through a DOE/NASA interagency agreement) with project management responsibility for the PAFC projects under the direction of DOE.

Question 2: It seems that the Fuel Cells program has achieved great successes especially in Phosphoric Acid fuel cells. I have noted that between FY 1982 and FY 1986, the Administration has requested only $70.6 million, and Congress has appropriated more than $181.6 million. If it were not for the congressional appropriation, what would be the status of the fuel cells program today?

Answer: If Congress had not appropriated the additional funds it is possible that the status of the fuel cells program may be the same as it is today. The Department believes that with a lower level of Federal funding, a higher level of private sector funding would have been required to achieve the same rate of advancement and that the private sector interest would have been great enough to provide the additional funding.

Question a: DOE is requesting only $5 million in FY 1987 for this very promising technology, both in power generation and transportation. Does DOE really have a consistent plan for this R&D?

Answer: The DOE plan addresses those R&D activities which are considered promising but unlikely to be pursued by the private sector due to their high risk and the long lead time required before investors earn returns. The policy of funding only promising high risk, long term R&D has been consistently articulated by the Administration. Commercialization of fuel cells continues to be viewed as the responsibility of the private sector.

Question b: What about the FY 1986 deferral of $22 million?

Answer: The deferral has been revised and will be used to offset FY 1987 budget requirements. Of the $35.4 million appropriated in FY 1986 for the Fuel Cells program, the Department has deferred $11.6 million including $6.8 million for phosphoric acid systems, $3.8 million for molten carbonate systems, and $1.0 million for advanced concepts. In addition, $9.3 million of phosphoric acid systems FY 1986 appropriations for the 7.5 MW technology development is proposed for rescission instead of being deferred as previously reported. The majority of the deferrals and the rescission is related to phosphoric acid fuel cells (PAFC). In the PAFC program, the Department is continuing development of the 11 MW stack configuration "A" with the International Fuel Cells Corporation (IFC) in FY 1986 and FY 1987 utilizing existing funds. In addition, the competitive procurement for configuration "B" cell stack R&D will be funded using FY 1985 unobligated funds. For the molten carbonate program, the IFC contract for external reforming is funded to completion using FY 1986 funding. The Energy Research Corporation's direct fuel cell project is funded through the current contract period (Sept. 30, 1986) using FY 1985 funds. In addition, a competitive procurement will be issued in late FY 1986 to continue development of external and/or internal reforming molten carbonate stacks using FY 1986 funds and technology development continued into FY 1987 using FY 1987 funds.

Question c: What is your plan for the short-term and long-term goal of the program?

Answer: The overall goal of the Fuel Cells program is to support high risk, high payoff research and to assist in developing a technology base to permit private sector decisionmaking on a hydrocarbon fuel conversion technology based on fuel cells.

- In the near term, to develop viable fuel cell technologies relying on natural gas and/or distillate fuels.

- In the long term, to develop advanced concepts for the improved utilization of coal.

For both the near term and long term, the plan is to develop the key fuel cell building blocks so that the private sector can subsequently develop and commercialize systems for electric utility, industrial (including cogeneration) and on-site applications. The feasibility for use in transportation will also be explored.

Question d: Would you elaborate on the funding distribution and its adequacy for FY 1987?

Answer: The proposed FY 1987 funding for Fossil Energy's fuel cell program includes $3,400,000 for molten carbonate research and development and $1,600,000 for solid oxide. This funding level will permit continuation of one or more molten carbonate stack development efforts (dependant largely on the extent of private sector co-funding) and continuation of the tubular solid oxide development effort. A small effort on supporting research could also be maintained. We believe the FY 1987 budget request for fuel cells is adequate considering the significant Federal and industrial investment to date, the maturity of the of the technology and the current budget deficits.

Question 3: You have concluded that based on the technical maturity achieved today, there is no need for the two bills we're hearing today. You also stated that the government should provide a solid base of technology information for the industry to use to make market-oriented decisions. The users and manufacturers would agree that many of the advanced concepts are still at their infant stage. Are you providing the solid base information to the industry? And if their opinion being that the technology is still high risk and economically unjustifiable, how would you react to their judgment?

Answer: The results of fuel cells research and development is being made available through reports, seminars, workshops and informal communication among the developers.

Initial market entry of fuel cell powerplants appears to be hampered by a number of factors including: high capital costs associated with production startup; lack of assured market volume; reduced energy costs; excess power production capacity in some areas; and lack of a perceived large, near-term competitive advantage to potential users. The Administration regards the issues of market entry as a proper role for the private sector once the technologies involved have been developed to the proof-of-concept stage.

Question 4: You have bragged about the international interest and involvement in your testimony, especially International Fuel Cells (IFC) corporation jointly owned by UTC and Toshiba. What is the status of the fuel cells program in Japan? Are you concerned about DOE funded technology being transferred to Japan via joint adventure? What is the market outlook in the short-term and long-term for U.S. manufacturers? And what should we do about the technology transfer to our competitors?

Answer: The Japanese Government and companies in Japan have very active fuel cell development programs. Although fuel cell research and development (R&D) has been underway in Japan for about 25 years, their major effort began in 1981 with a six year program in the "Moonlight Project" funded at 11 billion yen ($58 million in U.S. dollars at 190 yen/dollar). Two types of 1 MW phosphoric acid power plants (high pressure for electric utility and low pressure for on-site and industrial uses) are to be tested beginning in autumn of 1986 with completion in 1987. A new phosphoric acid fuel cell (PAFC) R&D program in the "Moonlight Project" is to be started in 1986. Molten carbonate stacks of 1 kW were tested in 1985 and 10 kW stacks are to be tested in 1986. Solid oxide modules of 100 to 500 watts have been tested. A second phase of R&D on molten carbonate and solid oxide is proposed to start in FY 1987.

In FY 1985, Congressional direction in the annual appropriations language required that contractors transferring technology abroad recognize the U.S. Government's contribution to the fuel cell technology development. To accomplish this, the Secretary of Energy approved a contract clause, entitled "Transfer of Fuel Cell Technology to Foreign Entities," to be added to all contracts using FY 1985 and all subsequent funding. This clause requires the contractor to obtain adequate recognition of the U.S. support in any contracts, licenses,

or other agreements involving foreign technology transfer. The Assistant Secretary for Fossil Energy must be notified in advance of the adequate recognition obtained before any contract, license, or other agreement can be formalized. Examples of adequate recognition include (1) performing the initial manufacturing of a product on U.S. soil, or (2) providing research results from foreign testing to the U.S. The Department believes that undesirable technology transfer can be avoided with the cooperation of the private sector. It is expected that technology advancements that occur abroad will be sought by developers in this country as well and will offer trade opportunities for U.S. developers.

The market outlook for U.S. manufacturers is expected to be dependant upon the willingness of the manufacturers to aggressively pursue business opportunities. The short term outlook could involve high market prices associated with initial high production costs and a resulting early market entry which is limited to specialty applications. An option by the manufacturers to delay the recovery of the initial high costs could result in lower early market prices and a more rapid expansion of the market. Long term market prospects are apparently attractive judging by the investment decisions being made in this country and abroad.

This Administration has provided a policy to avoid unnecessary constraints to free trade. We believe that sufficient means exist to prevent uncompensated technology transfer while still allowing for

trade and technology transfer into this country on a reciprocal basis. It appears prudent to continue to observe and monitor events on this issue.

Question 5: You have stated that "PEM-based fuel cells are the most promising technology for widespread use in the transportation sector" and "problems remain to be solved." If all the benefits can be realized as envisioned for the personal vehicles, what is your specific plan for this research? What is DOT's effort in this research? What is the U.S. auto manufacturers effort in this research?

Answer: In order to realize the potential benefits envisioned for vehicles, the Conservation and Renewable Energy program is addressing the following problems with PEM fuel cells:

a. size and life of the reformer and its responsiveness to varying loads;

b. cost and life of the membrane;

c. amount, life, and cost of the electrocatalyst required;

d. water management in the membrane and associated power characteristics.

One recent accomplishment is a decrease in the amount of catalyst required by a factor of ten.

The DOT Program is a study whose goal is to put a phosphoric acid fuel cell in a bus. This study is well coordinated with the Conservation and Renewable Energy program since the study is being carried out by Los Alamos National Laboratory, the CE prime contractor.

General Motors funded a study at Los Alamos National Laboratory and, as a result, has concluded that PEM fuel cells are best suited for transportation. General Motors has formed an inter-division committee, and company-funded research is underway at the central research laboratory.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of

C:LMpv

Honorable Pete V. Domenici
Chairman
Subcommittee on Energy Research
and Development
Committee on Energy
and Natural Resources
United States Senate
Washington, DC 20510

MAR 19 1986

Dear Mr. Chairman:

In connection with the February 24 hearings held by the Subcommittee on Energy Research and Development on Senate Bills, S. 1686 and S. 1687, NASA was asked to provide information about its fuel cell research activities. A summary of those efforts follows.

Several previous NASA missions (e.g. Gemini & Apollo) have used fuel cells as primary power sources. Currently, the shuttle is the only space system using fuel cells. Each orbiter has three hydrogen-oxygen fuel cells which have relatively recently been upgraded to produce 18KWe each. The units are normally operated at approximately 5 KWe in order to extend their life. Under these conditions, life of the units is expected to be 2500 hours or twelve missions before refurbishment.

NASA's principal fuel cell technology development effort is being conducted under the Space Station advanced development program and involves technology development for a regenerative fuel cell (RFC) for storage of electrical energy on board the Space Station. In fuel cells, power is produced electrochemically by combining hydrogen and oxygen fuel to produce water and electricity. The fuels are stored in tanks and limited in quantity thus limiting mission duration. The RFC couples a fuel cell (which produces power on the dark side of the orbit) with an electrolyzer. The electrolyzer uses electrical energy from a generator (e.g., a solar array) on the light side of the orbit to decompose the water back into hydrogen and oxygen. The cycle is closed so that water, hydrogen, and oxygen do not need to be replenished.

The Space Station RFC advanced development program consists of two main tasks. The component technology task, managed at NASA's Lewis Research Center, will develop cell technology and perform endurance testing of fuel cells and electrolyzers. Cell current collectors, frames and matrices for long life, reliable operation will be developed and will be components tested at the cell, stack and subsystem levels. Solutions to critical cell

technology problems are anticipated. Another major contribution of the advanced development program is expected to be an enhanced endurance test data base to confirm Space Station life and reliability requirements for regenerative fuel cell energy storage.

At NASA's Johnson Space Center, the engineering model development task team will design, fabricate, and test a Space Station RFC Engineering Model. The engineering model will incorporate several advances in the state-of-the-art over the orbital technology electrolyzer cell. Efforts will include fuel cell "stack-up" to higher voltage utilizing long life matrix and systems integration and testing to demonstrate space environmental usage of the electrolyzer. The expected result is an engineering model of about 10 kilowatt power level containing a fuel cell subsystem, and electrolyzer subsystem and reactant storage subsystem. This prototype will be integrated and automated to perform as an energy storage system.

The Office of Aeronautics and Space Technology has two technology efforts in the area of hydrogen-oxygen fuel cells. The first is related to higher performance primary fuel cells and the second is in the area of advanced regenerative fuel cells. Both are focusing on the electrocatalyst for the oxygen electrode.

A long life, high performance catalyst is being developed to extend the upper temperature limit of operation of primary fuel cells. This would result in reduced weights and increased efficiencies for these systems for upcoming missions, such as the aerospace plane and the orbital transfer vehicle when compared to state-of-the-art hardware as used aboard the space shuttle.

An improved version of a regenerative fuel cell is the focus of the second technology effort. Due to limitations on the oxygen catalyst, a separate fuel cell section and water electrolysis section is now required. The development of a catalyst material that would operate in both modes would not only permit the simplification of the overall system but would also allow the consideration of systems with no moving parts. These advanced regenerative fuel cell systems would be of interest for future geosynchronous satellite systems where long term unattended life times are required.

More advanced concepts are being investigated as well. Regenerative fuel cells based on hydrogen and bromine rather than hydrogen and oxygen offer the potential of higher efficiencies when compared to contemporary concepts. This is a consequence of the extremely reversible nature of the bromine electrode compared to the oxygen electrode. A second advanced concept that is being investigated is the use of highly compact assemblies of cells which are called monoliths. These concepts promise very lightweight power sources for special short term applications.

Preliminary system designs and weight studies are being carried out as well as exploratory cell and catalyst development in the case of hydrogen-bromine.

We appreciate the opportunity to provide this information on an important area of research, and would be pleased to reply to questions from the Subcommittee as would be helpful.

Sincerely,

John F. Murphy
Assistant Administrator
for Legislative Affairs

EPRI
Electric Power
Research Institute

March 26, 1986

BY FEDERAL EXPRESS

Senator Pete V. Domenici
Chairman, Subcommittee on Energy
Research and Development
United States Senate
Washington, DC 20510

Dear Senator Domenici:

Your questions in follow-up to my testimony at the 2/24/86 Subcommittee hearing on S.1686 and S.1687 reached me from my office while travelling on EPRI business. Recognizing the time constraints under which the Subcomittee on Energy Research and Development is working, I am responding immediately. Please forgive me if my response is, therefore, less complete than it might have been with more time for preparation and better access to my information sources.

Regarding your first question, the utility industry and we at EPRI very much appreciate the large and continuous support the Federal Government has provided for research, development and demonstration (RD&D) of phosphoric acid fuel cell (PAFC) technology. With all due recognition for that commitment and the stage of development reached because of it, I feel that Administration Officials underestimate the seriousness of the commercialization dilemma. Consequently, they tend to underestimate the importance of continued Federal support for PAFC R&D to improve the reward/risk ratio for electric utilities as users and for prospective manufacturers of fuel cells.

An inadequate ratio keeps utilities from committing to this new technology--e.g. through subscription to the PC-23 program currently offered by the International Fuel Cell Corporation--despite the fact that utilities are becoming quite concerned about their ability to meet their customer's electricity demand in the 1990s. This concern stems from the current financial and institutional inability of utilities to initiate construction of new nuclear and coal baseload power plants--exactly the situation calling for smaller, efficient and rapidly deployed technologies like the fuel cell. However, for utilities any financial reward would come only after years because of the higher cost of early units, and the amount would in any case be limited by regulation. The "reward" of being able to serve customers more effectively than, e.g., with rapidly installed, relatively inefficient combustion turbines is more than offset by risks: some remaining risk that fuel cells (especially early units) may not meet the cost, performance and reliability requirements, and the consequent risk that regulators will hold utility management and shareholders financially responsible for the lack of prudence shown by committing to a basically untried technology.

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One important way of reducing these risks is to reduce fuel cell capital costs and increase reliability through continued technology R&D. Support of such R&D is an appropriate role for the Federal Government. The "lack of prudence" risk could be limited or entirely eliminated by appropriate regulatory treatment of the costs of fuel cells (and other new technology). For example, the extra costs associated with early units might be included under R&D or in other categories of costs that are recoverable quickly through appropriate rates, without the possibility of future disallowances. This approach would be an example of the "incentive" and "regulatory improvement " referred to in your letter.

From a manufacturer's standpoint, the rewards (profits) promised by fuel cells at present appear inadequate or, at best, highly uncertain. For the reasons mentioned above, it is unclear whether a sufficiently large utility market for fuel cells will develop within the time a business venture has for recovering an adequate return on its investment in development and commercialization. Since the market is so uncertain, aggressive forward pricing of the technology to help stimulate the market clearly is extremely risky and thus unlikely to occur. Again, R&D to reduce costs and improve the technical prospects for success can make important contributions to reducing this financial exposure and risk.

For the U.S. developers of fuel cells--primarily IFC but also Westinghouse and ERC--time is an important aspect of risk. There are vigorous programs of fuel cell RD&D in Japan, and the technical lead of the U.S. is being reduced. If U.S. manufacturers are to convert their current technical lead into strong business positions in the U.S. and international markets, it is very important that all required development, commercialization and regulatory activities be carried forward as expeditiously as possible. Delays--including the deferral of Federal funding for technology improvement R&D--must be avoided if at all possible.

Obviously, any measures such as regulatory considerations, favorable tax treatment, etc., that would encourage utility commitments to fuel cells would be perceived as risk-reducing by the prospective manufacturers. Finally, Federal assistance in underwriting the incremental costs of early units--perhaps to be repaid once production cost learning has been achieved--could be a key factor in stimulating utility commitments and in reducing manufacturers' risks.

You inquired regarding fuel cell commercialization in Japan. While I cannot give you complete detail, several facts suggest that the situation in Japan is more favorable than in the U.S.:

- Utility load growth appears to be more predictable, and utilities appear to be in a better financial position to commit to future generation additions.

- Japanese utilities are planning to use substantial quantities of liquified natural gas (LNG) for power generation through the rest of this century. LNG is an ideal fuel for fuel cells which, in turn, will utilitize LNG more efficiently and cleanly than combustion-based power generation options.

- Japanese government expenditures for PAFC development under the "Moonlight" program are still growing. Specifically, two 1 MW demonstration units are being developed under a coordinated government-private sector effort, with participation of four major Japanese companies.

- Although first developed and applied in the U.S., the fuel cell is a technology well suited to Japanese capabilities for engineering and automated manufacturing of quality components in high volume and at low cost.

Regarding your second point, on private-sector cost sharing and appropriate levels of Federal support, more than half of the funding provided to date for PAFC RD&D has come from the private sector, a remarkable fact in view of the longer-term, technically risky efforts involved in fuel cell development over the last 15 years. The main reason undoubtedly is the private sector perception of the unique benefits fuel cells will be able to provide.

However, manufacturers and utilities in the U.S. are now faced with the need to cover the costs for design, fabrication, deployment, warrantees, operation and maintenance of early commercial fuel cell power plants--costs which will be much higher than past Federal RD&D support levels. Beyond the modest funds (approximately $2.5 million per year) EPRI expects to provide, there simply is no private sector capability left for support of PAFC technology R&D. We believe that, that in the near term, Federal support of $10 million per year for each, the IFC and the Westinghouse program, is appropriate and necessary for timely progress toward commercially viable technology.

Over the longer term, a number of promising avenues to further increase performance and/or reduce costs of PAFC and related technologies exists, including improvements of catalysts, more stable and higher-performance support structures, advanced electrolytes, as well as more advanced balance-of-plant technologies (reformers, thermal management systems, controls, etc.). Federal support of this type of work at a level of about $2 million per year, coordinated with EPRI, utility and manufacturer funding, is highly desirable.

Beyond the scope of my response which focuses on PAFC technology, there are major opportunities for advancing the technology of molten carbonate and solid oxide fuel cells--concepts with ultimate potential for extremely high efficiency using natural gas and coal derived fuels. Federal support of approximately $8-10 million per year for molten carbonate and $3-5 million for solid oxide fuel cell development is essential if the promise of these technologies is to be realized over the next 10-15 years.

Finally, I would like to comment briefly on S.1686 and S.1687, per your request. Regarding S.1686, fuel cell systems have several charateristics that will make them logical choices for utilization of renewable resources: fuel flexibility, economic viability in capacities that can match the dispersed production of fuel from biomass, solar energy and wind, and operating flexibility. Federal support for a program of R&D to enhance the viability of fuel cells for such applications thus is desirable. One caveat is that this R&D should focus on applications of prospective economic competitiveness, and it should be closely integrated with the technology programs aimed at the major applications. It would not seem wise at a time of severe budget constraints to spend $5 million on fuel cell technologies and applications that do not meet these criteria.

Regarding S.1687, including fuel cells explicitly among the cogenerating facilities qualifying under PURPA appropriately recognizes the particular potential of fuel cells as prime movers for economic cogeneration of electricity and heat over a wide range of capacities. The other modifications proposed under S.1687 also constitute useful references to fuel cells; I especially endorse the one recognizing the value of the experience gathered in the permit process of the New York City Fire Department. Finally, I believe that recognition of the export potential of fuel cell systems is important. It does seem unnecessary, however, to restrict the proposed language to the export market potential of fuel cells integrated with renewable power technologies since fuel cells have export potential well beyond these applications.

I hope that this response can assist your considerations in finalizing budget and other legislative proposals concerning fuel cells. Please do not hesitate to call me at (415) 855-2547 should you require clarification or additional information on any of the issues I have tried to cover.

Sincerely yours,

Fritz R. Kalhammer

Fritz R. Kalhammer
Vice President
Energy Management & Utilization

FRK:mct

gas research institute

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DAVID O. WEBB
Senior Vice President,
Policy and Regulatory Affairs

March 19, 1986

The Honorable Pete V. Domenici, Chairman
Subcommittee on Energy Research and Development
Energy and Natural Resources Committee
U.S. Senate
SD-317 Senate Office Building
Washington, D.C. 20510

Dear Senator Domenici:

I have attached GRI's responses to the follow-up questions your Subcommittee submitted to complete the record for the February 24, 1986, hearing on S.1686 and S.1687.

GRI appreciates the opportunity to appear before your Subcommittee to provide information on GRI's fuel cell research which it cofunds with the Department of Energy.

Thank you very much for your consideration.

Sincerely,

David O. Webb

David O. Webb

/mha
Attachment
cc: K. P. Lau

GRI ANSWERS TO QUESTIONS RESULTING FROM
FEBRUARY 24, 1986, TESTIMONY BEFORE THE
SENATE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

Question 1:
Do you think that there is adequate coordination among all organizations in fuel cells R&D? What areas of coordination can be improved to ensure that the best result is achieved with the reduced funding?

GRI Answer:
GRI believes that adequate mechanisms are in place to ensure satisfactory coordination among all organizations involved in fuel cell R&D. To date, many organizations have made significant commitments to fuel cell development, including DOE, NASA, the Department of Defense, GRI, and EPRI. All are members with GRI of an ad hoc National Fuel Cell Coordinating Group. This group coordinates fuel cell technology development and program activities at the national level. Several other organizations also are active supporters of fuel cell research, including Niagara Mohawk Power Corporation, the New York State Energy Research and Development Authority (NYSERDA), Southern California Edison, and Pacific Gas and Electric Company. GRI will continue to coordinate its fuel cell R&D with all of these other organizations and will focus on issues they do not directly address. Coordination will also be maintained for those GRI project areas dealing with electrochemistry, materials, engine-driven cogeneration, and heating and cooling systems.

Question 2:
You intend to fund parallel research of both the Westinghouse tubular concept and Ceramatic/IFC hot-pressed flat plate approach and to monitor Argonne's monolithic solid oxide fuel cell. What is the mechanism for providing funding to the research organizations--directly or through DOE?

GRI Answer:
Beginning in 1986, GRI plans to begin contract negotiations with Westinghouse to fund research on its solid oxide fuel cell tubular concept and with Ceramatic to fund research on its solid oxide hot-pressed flat plate approach. These GRI programs will capitalize on ongoing DOE research but will address component and system issues directly related to gas fuel cell cogeneration systems. The mechanism for funding will be direct contracts between GRI and the companies.

At this time GRI does not anticipate funding the Argonne efforts in monolithic solid oxide fuel cells, but GRI will continue to monitor the research progress through coordination systems that are in place.

Question 3:
Japan is vigorously pushing for fuel cells R&D. Does GRI have any technology exchanges with its counterpart in Japan? What have you learned?

GRI Answer:
GRI has informal exchanges with the gas companies in Japan (Osaka and Tokyo Gas) that provide general information on technology development related to the gas industry. Since the fuel cell effort in Japan is primarily sponsored by the Japanese government, GRI does not have direct access to this information.

Through the informal exchanges, GRI understands that the fuel cell research program the Japanese government sponsors consists of research on multimegawatt phosphoric acid fuel cell systems for central station power generation and on 200 kW phosphoric acid fuel cell systems for cogeneration and remote island applications. Two government-sponsored teams will build and test prototypes of the multimegawatt systems in late 1986. Prototypes of the 200 kW onsite systems are scheduled to be built and tested in 1987.

Best estimates are that the Japanese government funds approximately $15 million per year for phosphoric acid fuel cell development.

THE FUEL CELL USERS GROUP
OF THE ELECTRIC UTILITY INDUSTRY, Inc

1101 Connecticut Avenue, NW
Suite 700
Washington, DC 20036
202/457-0868

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Technology Transition Corporation
Executive Director

March 19, 1986

The Honorable Senator Peter V. Domenici
Chairman, Subcommittee on Research
and Development
Committee on Energy and Natural Resources
Senate Dirksen Office Building
Room 434
Constitution Avenue, NE
Washington, DC 20510

Dear Senator Domenici:

Thank you for the opportunity of responding to the additional questions resulting from your Subcommittee's February 24, 1986 hearing. My answers are enclosed.

If I can be of any further assistance, do not hesitate to let me know.

Sincerely,

Jeffrey A. Seffass

for Ted H. Light
General Manager
Governmental Affairs
Public Service Electric
& Gas Company
Newark, New Jersey

THL/rcp
enc.

Q. 1. Can you elaborate on the offer by IFC to the utilities that could lead to the initial production of the first commercial scale fuel cell power plants?

A. The offer that International Fuel Cells has presented to the electric utilities is for the sale of 11 MW fuel cell power plants. The power plant has the following characteristics:

New power output	11 MW ac
Output voltage	13.8 kV ac
Heat rate	8300 Btu/kWh (HHV)
Power Change Rate	1 MW/sec
Fuels	Natural gas - standard Dual fuel - optional
Operation	Automatic, unattended
Water make-up	None
Exhaust purity	NO_x - .00s lb/10^6 Btu max SO_x - trace Particulate - trace
Noise	60 dB (A) at 100 feet from perimeter
Heat rejection	recoverable for use

IFC proposes to manufacture and sell 23 market entry power plants; the first three are termed prototypes and the next twenty are termed semi-production units. The total 250 MW of capacity will be on-line by 1992 with the first prototype operating in 1989.

The nature of the offer is a shared risk and cost proposal. The utility industry is being asked to pay a higher cost for these early units and thereby accept some of the risk that the technology will be fully commercial soon. (Conversely, the utilities will be unlikely to pay the higher costs of these early units if there is a low expectation that we will able to use this technology, with competitive costs, in the mid-1990s). The utilities, on the other hand, are not being asked to accept the risk of operation of the units, nor are we being asked to provide progress or up-front payments. We will pay only upon completion of a negotiated acceptance test.

The cost of these units has not yet been negotiated by any utility and, therefore, any figures must necessarily be viewed as preliminary. Discussions with members of the Fuel Cell Users Group have yielded an average price of about $2000 per kW as viewed by the utilities. Exactly how the costs of this program are shared by all participants has yet to be determined.

Q. 2. Your comment on the utility resources to be invested to purchase, install and operate early market units of fuel cells seems to indicate that you are sharing the cost already on fuel cell development. What level of funding should Federal government provide in the continuation of fuel cell development?

A. As stated above, the utilities will pay the high costs of these early market units only if there is an expectation that the costs (capital and operating) can be low enough to yield a broadly useful generator. To continue the technology development progress of IFC and to continue the development of the competitive Westinghouse technology requires federal funding of at least $10 million per year for the electric utility, multi-megawatt programs. The private resources will be fully committed to the engineering, manufacture and purchase of the market entry units, leaving little room for private support of continued technology development.

Q. 3. When do you expect to publish your revised study of the market for fuel cells?

A. The market study referred to in my testimony will be completed by June, 1986 and published by the Electric Power Research Institute by September, 1986.

Q. 4. In your testimony, you have stated "The change to PURPA should be considered with a review of the total PURPA program." Would you elaborate on it?

A. The electric utility industry has viewed PURPA with some concern and without unanimity on all of the issues. Among the concerns often cited are those of the limitation on utility ownership and the strict notion of "avoided costs." When the Management Committee of the Fuel Cell Users Group of the Electric Utility Industry, Inc., discussed S. 1687 with its amendment to PURPA, it was felt that we should withhold our support of this amendment because of the much greater concern felt by the utility industry over other PURPA issues.

A detailed discussion of these issues is beyond the scope of the Users Group.

Westinghouse
Electric Corporation

1801 K Street N W
Washington DC 20006

April 7, 1986

Honorable Pete V. Domenici
United States Senate
Room 434
Senate Dirksen Office Building
Washington, DC 20510

Dear Senator Domenici:

Enclosed are responses to the follow-up questions your Subcommittee prepared on testimony provided by Dr. George F. Mechlin, Vice President, Research & Development, Westinghouse Electric Corporation. These responses are from your hearing on Fuel Cells held on Monday, February 24, 1986. Westinghouse was most please to have an opportunity to participate in your hearing on this exciting and promising new technology.

We look forward to working with you, your Subcommittee and staff to help assure that the United States continues its worthwhile energy technology development efforts.

Sincerely,

John A. Gruver
Manager, Government Programs

cc: Dr. G.F. Mechlin
K. P. Lau

March 24, 1986

Answers to questions of Senator Pete V. Domenici, Chairman, Subcommittee on Energy Research and Development.

1. It is an interesting analogy between the Aviation industry and fuel cells in relation to the market and the competition from Japan. What indication proves your observation that the United States is the undisputed leader in fuel cell technology?

Answer:

A. Two multi-megawatt units have been built by a U. S. company, none by a Japanese company. A Japanese electric utility purchased one of these units for demonstration purposes on their system.

B. Forty-six smaller "on-site" fuel cell systems were built and field tested by a U. S. company. No comparable units have as yet been field tested using Japanese technology. Two Japanese gas utilities purchased and tested several of these units in Japan.

C. A large Japanese manufacturer has licensed "air cooled" system technology from a U. S. company.

D. Another large Japanese manufacturer has formed a "joint venture" with a leading U. S. technology developer.

E. Still another large Japanese manufacturer has undertaken with us to provide their customer - a Japanese electric utility - with a demonstration unit.

F. My company's technical experts attend public and private meetings and conferences all over the free world and have related their estimate of the relative positions of U. S. and Japanese technology for both nearer term and advanced technology systems. A Japanese conference on fuel cells held in mid January purported relating the latest in Japanese technology. Two Westinghouse representatives were present. Their conclusion was U. S. technology is ahead in near term systems and way ahead in advanced systems.

2. The business community has regarded energy research as a very risky and unpredictable undertaking. Therefore government R&D support is essential in reducing the high risk. What level of funding is appropriate to reduce risks? What is Westinghouse' share of the budget in fuel cells?

Answer:

The FY84, 85 and 86 budgets in the $35-40 million range have allowed for significant technology advancement although cannot be considered a level large enough for an appropriate aggressive thrust. This type thrust must include obtaining customer acceptance of units before adequate capital investment is made for process mechanization for cost reduction, i.e. initial high cost units have to be evaluated in potential applications.

In the Westinghouse Fuel Cell programs, almost half of the total development investment has been made by the private sector. Of that private sector amount, Westinghouse has provided slightly more than 60%. As these programs move closer to commercialization, the Westinghouse share of the total investment will increase not in percentage points but by several times that of the Goverment. Extensive, complex, special tooled and partial automated manufacturing facilities and significant capital investments are required to make fuel cells competitive and reliable. Westinghouse believes the benefits of Fuel Cells warrant the Goverment Private Sector team investment necessary to commercialization.

3. In what specific areas of fuel cells research is Westinghouse now undertaking?

Answer:

Westinghouse has two major strategic technical thrusts to our fuel cell program. The first involves the nearer term phosphoric acid type utilizing an air-cooled pressurized design intended principally for electric utility dispersed power plants of 7.5 Mw units. The second is the advanced solid oxide fuel cell type which could have a very broad range of applications including commercial and industrial cogeneration systems as well as all electric electric utility power plants. This latter type could probably compete in applications requiring from several hundreds of kilowatts plus high quality heat to hundreds of megawatts. (The larger units perhaps several years after the smaller ones.)

George F. Mechlin
Vice President
Research & Development
Westinghouse Electric Corporation

COLLEGE OF ENGINEERING

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Blacksburg, Virginia 24061

DEPARTMENT OF ELECTRICAL ENGINEERING (703) 961-6646

Senator Pete V. Domenici
Chairman, Subcommittee on
Energy Research & Development
United States Senate
Washington, D.C. 20510

18 March, 1986

Dear Senator Domenici:

In response to your letter dated 12 March, 1986 I am happy to supply the answers to the follow-up questions on renewable energy and fuel cell integration. This is with reference to your subcommitte hearing held on 24 February, 1986. I am also attaching a revised copy of my written testimony that was submitted earlier. I would like to request that this revised testimony be included in the hearing record.

Thanks for your attention.

Sincerely,

S Rahman

Saifur Rahman
Associate Professor

Response provided by Professor Saifur Rahman - VPI&SU

Q.1 What is the optimum size of fuel cells for Photovoltaics-Wind energy and fuel cell system?

Ans. The size has to be determined on the basis of four factors.

(i) Characteristics of load to be served,
(ii) Size of photovoltaic energy system,
(iii) Size of wind energy system, and
(iv) Long term variation of solar and wind energy resource in the area.

For example, let us assume that we want to serve a certain load using PV-wind energy and fuel cell hybrid system. It is a stand-alone system without any backup. Once the load characteristics are known, the PV and wind characteristics have to be examined to see what percentage of the load can be met economically by these sources. Suppose we have a combination of residential and commercial load that varies between 300 and 1000 kW. Let us assume our analysis shows that we can meet between 100 and 800 kW by the PV-wind combination. So the fuel cell power plant has to provide between 200 and 900 kW. Now the question is - should we have a 900 kW fuel cell to supply a 1000-kW peak load in the presence of PV and wind based generation? If you want guaranteed reliability of supply and donot want any load control, the answer is yes. If on the other hand, you can live with some loss of reliability and want to exercise some load control when wind speed and sunshine are not as expected, fuel cell size can be substantially less than 900 kW. How much less? That will depend on system characteristics. Research work is under way at Virginia Polytechnic to develop computer models to simulate various operating conditions and answer some of these questions.

Q.2 What can we learn from PV-fuel cell systems in Space Programs?

Ans. Both PV and fuel cell systems have been used in space programs. But, to my knowledge, they have not been used as a hybrid system to match the variable output of the PV array as we perceive for terrestrial applications. The intermittent nature of PV output due to changes in cloud cover is not a problem in space. However, we can learn about the fuel consumption, fuel substitutability, heat output and response rate of fuel cell power plants from space programs. These issues have to be looked at for determining the applicability of fuel cells to work in concert with photovoltaic and wind energy systems.

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

March 18, 1986

Senator Pete Domenici, Chairman
Subcommittee on Energy Research and Development
434 Senate Dirksen Office Building
Between 1st and 2nd Streets, NE
Washington, DC 20510

Dear Senator Domenici:

Your letter with questions to follow up the February 24 Energy Research and Development testimony arrived yesterday. I am pleased to offer these responses:

Q. Your testimony seems to indicate that "monolith" oxide fuel cell is the only technology that has the capability to capitalize on all the benefits fuel cells promise. Do DOE, other researchers, and the automotive industry share your observation?

R. I don't believe that any one fuel cell can best serve all applications. The monolith is a new development, and not widely known outside the fuel cell community. Experts who have examined the idea usually agree that the monolith power plant, if successfully developed, would have the requisite low cost, power, and simplicity to serve large markets, including transportation, that are not accessible to other known fuel cell types. DOE fuel cell managers generally seem to be of that opinion, as do a growing number of technologists in the automotive industry.

Q. When can monolith oxide fuel cells successfully be applied to the automotive marketplace?

R. The family automobile is, because of its intensely competitive and cost-sensitive nature, one of the last applications in which one would expect any new kind of power plant to compete. With adequate funding, it is reasonable to expect initial uses (probably military) in the early 1990's and first automotive applications at or before the turn of the century.

Q. I understand that the processing technology of ceramic, for fuel cell applications, is the major drawback. What is the adequate funding for ceramic research?

R. Yes, by far the greatest uncertainty in monolith development is associated with the fundamental issues of fabrication. Perfecting the fabrication processes and tailoring the materials must be and is the subject of early monolith development. At present, the DARPA research funding of $2 million/year is just adequate to maintain a viable program. To meet the schedule of early 1990's first use, an orderly increase in monolith ceramic research to $7 million/year is advisable.

Q. Is all your work on monolith funded by DARPA? Is Argonne also doing research work on oxide fuel cells for DOE? If so, is there any coordination between the two efforts?

R. Yes, all our work on monolith is funded by DARPA. From 1979 through 1985, we provided DOE with technical advice for program direction and a small amount ($250K total) of research in oxide fuel cells. Last fall, we requested that DOE terminate our program advisory function to avoid possible future conflict of interest (or appearance thereof) between that function and monolith development. DOE agreed and discontinued oxide-related work at Argonne. We maintain good communications with DOE and keep key DOE people apprised of monolith progress.

Q. Based on your observation of foreign competition on fuel cell technology, what is your opinion on their programs draving heavily on published U.S. results and on cooperative agreements with U.S. companies?

R. Most foreign programs are based on U.S. results, both those generally available and, apparently, purchased information. In some cases it is possible to identify the designs of the individual U.S. manufacturer or research organization in foreign laboratories. Access to U.S. information cannot help being a great advantage to foreign competition. It allovs them to make strategic decisions vith minimal investment, but it will not entirely avoid the necessity for carrying out some R&D themselves.

Those international agreements that maintain our ability to sell the hardware we have developed, both in the U.S. and in nations not party to the agreement, seem to be generally beneficial for us. Market-entry fuel cell plants need all the financial backing and early market applications that can be found. At present, we have a technological lead in all practical fuel cell types. We can maintain a dominant position if we simply pursue a vigorous program to capitalize on our existing advantage.

If you want any further information that I can provide, please do not hesitate to write or to call me at 312-972-5573.

Sincerely,

John Ackerman

John Ackerman, Associate Director
Chemical Technology Division

JPA:mb

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DATE: March 25, 1986
IN REPLY REFER TO: ERA/AES:86-44
MAIL STOP: F682
TELEPHONE: (505)667-3973

Senator Pete V. Domenici
Chairman, Subcommittee on Energy
Research and Development
Committee on Energy and Natural Resources
United States Senate
Room SD 317
Washington, DC 20510

Dear Senator Domenici:

As requested in your March 12, 1986 letter, I am responding to the follow-up questions resulting from the hearing receiving testimony on S.1686, the "Renewable Energy/Fuel Cell Systems Integration Act of 1985" and S.1687, the "Fuel Cells Energy Utilization Act of 1985". If you or your staff require additional information, please do not hesitate to ask.

Thank you for the opportunity to express my views on this important technology.

Sincerely,

Michael E. Berger
Deputy Associate Director
for Alternative Energy Sources

MEB/fma

enc: as stated

cys: J. R. Huff, E-11, D429
G. Maestas, ERA/AES, F682
CRMO (2)

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Los Alamos National Lab
Dr. Michael Berger

1. Indeed, over 60% of U.S. petroleum usage and the majority of air pollutants come from the transportation sector. What has been the financial contribution by the automotive industry in this promising technology?

2. Is there any market study for fuel cells in vehicular application?

3. You have anticipated that an advanced fuel cell application for transportation can be achieved in 5 years, and phosphoric acid fuel cell technology for bus applications in 3 years. You have also recommended a research budget of $4-5 million per year over 5 years. Is your recommendation for the advance fuel cells only, or for both personal vehicles and buses?

4. What do you mean by "it should be possible to have a coordinated program with participation by DOE, DOT and DOD?" Is there enough coordination among the groups now? What can be improved if not?

5. What is the safety, health, and environmental impact for the usage of phosphoric acid, hydrogen, and carbon monoxide in mobiles?

RESPONSE TO TESTIMONY ON S.1687

Michael E. Berger

1. Recently, General Motors Corporation (GM) has shown significant interest in fuel cells for transportation applications. GM has expended about $1.25M during the last two years and will allocate about $2M to fuel cell research in calendar year 1986. GM contracted directly with Los Alamos National Laboratory to review research results obtained thus far in the DOE program. The contract has been fulfilled satisfactorily at this time. GM had previously tested a fuel cell powered Electrovan in the early 1960's as a $2-3M program. The Englehard Minerals and Chemicals Corporation is expected to have a fuel cell powered forklift truck commercially available in about two years. Their total investment by then will be about $6-7M. A Belgian-Dutch consortium is currently involved in a $10-15M fuel cell bus program.

2. To our knowledge there has been no formal market study as such of fuel cell applications in the transportation industry. However, the GM effort is based largely on their assessment of the potential for the highly fuel efficient fuel cell to replace the internal combustion engine (ICE). Also attractive to GM is the fuel cell's use of methanol which is forecast to be more available and less expensive than gasoline in the next ten to fifteen years. A technological and economic feasibility study of fuel cells in buses is now being completed at Los Alamos National Laboratory for the Department of Transportation. Although not a market study per se, it will describe the costs involved relative to costs of diesel-powered buses currently in use.

3. The $4M per year program would focus on the advanced (proton exchange membrane, PEM) fuel cell and the advanced fuel processor. The research would be of direct benefit to the phosphoric acid system, particularly the fuel processor work. Due to its high power density, the PEM fuel cell is the power source of choice in the longer term for personal vehicles, trucks and buses as well as for mobile power supplies for the military. However, the phosphoric acid cell is more fully developed and is ready for near-term (three year) use in a larger vehicle such as a bus. A bus technology development program with a phosphoric acid fuel cell concurrent with the PEM research would identify system integration problems and lead to a prototype system for the eventual incorporation of the PEM cell. The modularity characteristic of fuel cells permits stacking of basic units to achieve the varying power requirements of personal vehicles, buses, and locomotives. It also facilitates replacement of one fuel cell type with another, e.g., phosphoric acid with PEM. Thus experience gained with a phosphoric acid integrated system would be directly applicable to a PEM system.

4. The current program in fuel cells for transportation is funded by the Office of Energy Storage and Distribution in the Department of Energy and involves mostly basic research on fuel cell electrochemistry. The DOE Office of Transportation Systems has participated in systems analysis and could become involved in systems development and integration. The DOT needs and requirements duplicate some of those in the DOE and it is in the interest of both agencies to develop a coordinated program. The DOD as a potential user of fuel cells can also benefit from generic research and should be encouraged to fund and participate in technology development.

Although Los Alamos has dealt with these agencies and has initiated a dialog among the DOE, DOT and DOD, current funding is not now sufficient to encourage closer cooperation. However, eventual partnerships in fuel cell development are clearly the most efficient approach.

5. The overall safety of methanol fuel cells in transporation is equivalent or better than that of internal combustion engines. However, this has not been demonstrated in crash situations. NO_x emissions from a fuel cell are not measureable and CO is produced in minute amounts. Ordinarily CO generation is at least a factor of ten lower than EPA standards. The hydrogen produced from the fuel processor is dependent upon fuel cell requirements and minor storage is anticipated for providing peaking power for acceleration. Environmentally, fuel cells have an advantage over internal combustion engines. In addition to low chemical pollution, they also are quiet, which is desirable for urban applications.

University of Hawaii at Manoa

Hawaii Natural Energy Institute
Holmes Hall 246 • 2540 Dole Street • Honolulu, Hawaii 96822

March 21, 1986

The Honorable Pete V. Domenici
Chairman, Subcommittee on Energy
Research and Development
United States Senate
Washington, D.C. 20510

Dear Senator Domenici:

Dr. Donald Topping passed on your questions to me for response. Incidentally, while your letter is dated March 12, and indicated a March 19 deadline, we only received it today.

1. What are your experiences with your 16 electric vehicles?

   We initially had major technical and human interaction problems with the EV's. More recently, we consolidated leadership under one program manager, and were able to receive hardware assistance from the USDOE. Our EV's are now among the best run fleets in the world.

2. You have pointed out the problems with the presence of carbon monoxide and unreacted methanol for mobile applications. What are the solutions for the potential problems?

   Our personal experience is quite limited, but discussions with SERI people indicate that R&D funds need to be continued to resolve these problems.

3. The Wind Energy Storage Test program intends to store hydrogen in compressed form. Are there any health, safety, and environmental concerns?

   As in all energy systems, there are trade-offs. We have taken special precautions in building design and personnel training. The heart of the matter is that alternatives such as windpower and solar photovoltaics are intermittent. Batteries will continue to be expensive for a long time to come. However, hydrogen shows considerable promise, particularly since this fluid can be used for multifarious operations, especially as a transportation fuel for "nearly" conventional engines.

AN EQUAL OPPORTUNITY EMPLOYER

Please do not hesitate to let me know if I can be of any additional assistance to your program. I have enclosed a copy of my testimony (and witness list) regarding hydrogen, should your subcommittee chance to hear the bill in the future. Aloha.

Sincerely,

Patrick K. Takahashi
Director

PKT:ek

Enclosure: H_2 Testimony and Witness List

cc: Senator Spark Matsunaga

TESTIMONY ON

H.R. 3899 - HYDROGEN RESEARCH AND DEVELOPMENT ACT

PRESENTED BEFORE THE

U.S. HOUSE OF REPRESENTATIVES

SCIENCE AND TECHNOLOGY COMMITTEE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

March 12, 1986

Patrick K. Takahashi, Director
Hawaii Natural Energy Institute

and

David L. Block, Director
Florida Solar Energy Center

Mr. Chairman and members of the Committee, my name is Patrick Takahashi and I am the Director of the Hawaii Natural Energy Institute (HNEI) and Professor of Engineering at the University of Hawaii. This testimony is being presented jointly with David Block, Director of the Florida Solar Energy Center. We strongly endorse the intent of H.R. 3899, as this initiative can greatly contribute to our nation's future energy security and provide for our air and space travel needs into the 21st century.

Five years ago, as Senator Spark Matsunaga's Special Assistant on Energy, Science and Technology, I assisted him in drafting the first hydrogen bill ever introduced in the U.S. Senate. H.R. 3899 is an improved version of the original. I thus am quite familiar with the contents.

Energy plays a much more important role in our economy than most people realize. The gas lines and double-digit inflation are now only bare memories, but we forget how our entire economic system was traumatized and national security compromised. These same effects will almost surely someday return to haunt us...unless steps are taken today to preclude future insults and inconveniences. The recent decline in oil prices has decreased the rate of inflation, spurred business recovery, and, really, has provided a reprieve period for our nation to prepare more wisely this time.

The unsettling bottom line is that no one can predict the price of oil. Chevron USA last year predicted that our country would in the Year 2000 be using as much oil as we were in 1973 at the time of the first oil crisis, but importing more than in 1973. Most of this petroleum would furthermore be coming from the Middle East. We, therefore, applaud you on H.R. 3899 for your perspicacity and vision.

Of all of the alternatives available, hydrogen can make the greatest contribution to future air travel, in part aided by having the highest energy content per pound of any fuel. Hydrogen from renewable energy,

furthermore, is benign to the environment, unlike the more conventional options used today. The major disadvantage is the present high cost of production. There are also unknowns regarding handling, storing and transporting the fluid. The proposed legislation will address these problems so that the private sector can over time gain confidence in bringing the technology to the marketplace.

It should be pointed out that hydrogen is in much wider use today than most people realize. More hydrogen is used in industry world-wide than any base metal except iron and steel, and any chemical other than sulfuric acid. Furthermore, hydrogen's 9% annual growth rate is far higher than any other commodity. In ammonia production, refinery operations, the space shuttle and a variety of other uses, hydrogen is already today an important niche feedstock.

HNEI, in cooperation with the Florida Solar Energy Center, is conducting a technology status assessment of hydrogen produced from renewable energy. The objectives are to:

- o evaluate the potential of renewable-hydrogen as a fuel;
- o investigate the assimilation of renewable-hydrogen into the overall energy economy; and
- o identify technologies and the research and development needed to provide such an option.

Attached is a paper HNEI just submitted for the World Hydrogen Energy Conference being held in Austria this coming July that discusses this assessment, which is being funded by the U.S. Department of Energy through the Solar Energy Research Institute. We are encouraged by the findings to date that hydrogen can maximize the benefits of renewable energy and serve as an energy bridge into the future. In addition, there are various nearer term applications for hydrogen, such as in the production of methanol for transportation.

Hawaii does offer a unique opportunity for hydrogen produced from renewable energy as an economic reality in a few key areas. In the longer term, more than 30% of the energy used in Hawaii, which is reflective of many island communities, and portends a future energy use pattern for the world, goes to power jetliners. We are, of course, very much interested in the aviation elements of your bill. In the nearer term, we are moving forward on a program to develop a test-bed plant to produce methanol from biomass.

Methanol is a carrier of hydrogen, is easily handled (like gasoline), and is readily suited to existing transportation systems. Ford Motor Company is producing 100,000 cars this year that can use methanol. Adding hydrogen to the process of gasification and conversion can double the amount of methanol produced from the same biomass feedstock.

Finally, HNEI is developing a program that will test and evaluate the use of methanol for a phosphoric-acid fuel cell to extend the range of one of our improved electric vehicle (EV) vans. We already have sixteen EVs in our fleet. In short, hydrogen, through methanol, is considered by some to be an almost now-technology.

Methanol and ammonia, another carrier of hydrogen, could also become the media to deliver energy produced from ocean thermal energy conversion (OTEC) to areas around the world. W.H. Avery of Johns Hopkins University's Applied Physics Laboratory points out in a recent article, "If the potential OTEC power were used to electrolyze water, and the hydrogen and oxygen produced were used onboard as feedstocks for ammonia or methanol production, the output would far exceed in heating value the present total energy demand of the U.S." (IJHE, Vol.10., No.11, pp 727-736). One estimate of the OTEC potential in Hawaii indicated that if we site one OTEC plant every 25 sq. miles in our economic zone waters, more energy could be generated than imported by the U.S. from OPEC.

Thus, the transition to a greater utilization of hydrogen, particularly from renewable energy, offers our nation the following advantages:

- o lessen our dependence upon undependable imported oil;
- o reduce the impact of future oil crises;
- o create major economic development opportunities and jobs;
- o improve the nation's balance of trade;
- o enhance the environment (and reduce the impacts of acid rain, the greenhouse effect, the problem of nuclear waste); and
- o enable the greater utilization of intermittent renewable energy resources.

In closing, federal support for hydrogen research and development is vital to fund the work that is needed: to reduce the cost of hydrogen production; resolve problems of transportation, storage and utilization; and provide the basis of a sound transition to effective use of this untapped resource. Our Hawaii State Legislature has provided initial funds for our hydrogen program, as they appreciate the potential that hydrogen has to our State's future. Congress needs to take a similarly enlightened view because only with a meaningful and continuous R&D program will our nation be able to transcend the energy roller-coaster ride of the past dozen years to a more energy secure future. We hope you will act favorabaly on H.R. 3899.

Thank you for giving me the opportunity to testify.

STATEMENT BY THE HONORABLE

DANIEL K. AKAKA

IN SUPPORT OF H.R. 3899

THE HYDROGEN RESEARCH AND DEVELOPMENT ACT

BEFORE THE HOUSE SUBCOMMITTEE ON TRANSPORTATION,

AVIATION, AND MATERIALS

MARCH 12, 1986

Mr. Chairman, I appreciate the opportunity to appear before the Subcommittee on Transportation, Aviation, and Materials in support of H.R. 3899, the Hydrogen Research and Development Act.

With me today is Dr. Patrick Takahashi, Director of the Hawaii Natural Energy Institute. Dr. Takahashi is no stranger to the halls of Congress, since he served as Special Assistant on Energy for Senator Spark Matsunaga from 1979 to 1982. I have known Pat since his days with Senator Matsunaga, and am grateful for the counsel he has provided me on many energy-related issues. You may be interested to know that during his tenure with Senator Matsunaga, Dr. Takahashi drafted the first hydrogen research bill, a precursor to H.R. 3899.

Some of you may wonder, "Why is there such strong interest in the development of hydrogen fuels in Hawaii?" The answer is rather simple.

Hawaii has long been recognized as a leader in developing and utilizing renewable energy technology, due to a concerted effort to lessen our heavy dependence on imported petroleum. Hawaii leads the nation in the production of electrical power through renewable energy. Since renewable energy resources are viewed as primary energy sources for converting hydrogen from its natural state into hydrogen fuels, Hawaii can play a central role in planning for a new era of hydrogen fuels. For this reason, I am happy to be a co-sponsor H.R. 3899.

It is inevitable that hydrogen will become the fuel of choice to satisfy a wide variety of the world's energy needs. The current estimate by the Institute of Gas Technology is that all proven fossil fuel resources will be exhausted by the middle of the next century. For this reason, it is essential that we make the transition to hydrogen fuels.

One recent event which will surely spur the development of hydrogen fuels is the federal government's research on the "trans-atmospheric vehicle" which could take-off from airports on the east coast, climb 70 miles to the fringes of space, achieve a speed in excess of mach 5, and reach Tokyo in under three hours. The President's budget request for fiscal year 1987 contains $138 million for research and development of the trans-atmospheric vehicle. This research program is divided between three federal agencies, NASA, the Air Force, and the Defense Advanced

Research Projects Agency. In FY 1988, it is expected that funding for this research initiative will grow to $220 million.

Despite the tragic loss of the shuttle Challenger and its crew, experts agree that at some point NASA will resume its launch schedule. NASA's shuttle program is the largest single user of hydrogen. In just over six minutes, a shuttle launch consumes one-half million gallons of liquid hydrogen. If NASA achieves its full capability for shuttle launches, hydrogen demand for the shuttle program will be 200,000 pounds per day.

The shuttle program, together with increased demand generated by hydrogen-fueled aircraft, provide ample justification for enacting H.R. 3899. While these two programs are the most prominent examples of large-scale uses of hydrogen, they are by no means the only applications for hydrogen fuels. In time, it is likely that hydrogen will become the dominant fuel to satisfy our world's energy needs.

Hawaii is already doing its part to develop technologies for the production of hydrogen fuels. Hawaii is the world leader in research on Ocean Thermal Energy Conversion (OTEC). OTEC is a solar thermal energy converter, tapping the energy resource created by the temperature difference between solar heated surface and polar cooled subsurface ocean waters. A recent paper in the International Journal of Hydrogen Energy concluded that OTEC plants could potentially provide many times

the annual U.S. power demand and constitute an ample resource for an eventual "hydrogen economy."

Methanol, a carrier for hydrogen, already is an important industrial product and is considered by many to be the most promising replacement for gasoline used in ground transportation. The Hawaii Natural Energy Institute recently conducted a technology assessment of hydrogen produced from renewable energy which determined that we can double the amount of methanol that can be produced from biomass through the addition of hydrogen to utilize all of the available carbon. Using this approach, the three million tons of sugarcane waste produced annually by Hawaii's sugarcane industry could be used to produce 300 million gallons of methanol. This could provide nearly three-fourths of Hawaii's annual fuel requirements for ground transportation.

Mr. Chairman, I hope I have given you some appreciation for Hawaii's keen interest in research and development of hydrogen fuels. Once again, I thank you for the opportunity to testify.

TRANSPORTATION, AVIATION AND MATERIALS SUBCOMMITTEE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U. S. HOUSE OF REPRESENTATIVES
WASHINGTON, D. C. 20515

Hearing:

H.R. 3899, the Hydrogen Research and Development Act

March 12, 1986
2:00 - 5:00 p.m.
Room 2325 Rayburn House Office Building

Witnesses

Honorable Daniel K. Akaka
Member of Congress
(Hawaii)

accompanied by:

Dr. Patrick Takahashi, Director
Hawaii Natural Energy Institute

ADMINISTRATION

Honorable Robert L. San Martin
Deputy Assistant Secretary for Renewable Energy
Office of Conservation and Renewable Energy
U.S. Department of Energy
Washington, D.C. 20585

accompanied by:

Dr. Donald K. Stevens
Associate Director
Basic Energy Sciences
Office of Energy Research

Dr. Raymond S. Colladay
Associate Administrator
Aeronautics and Space Technology
National Aeronautics and Space Administration
Washington, D.C. 20540

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Answers to Questions of
Senator Pete V. Domenici, Chairman
Subcommittee on Energy, Research and Development
March 21, 1986

Response requested per Subcommittee hearings on February 24, 1986.

1) Question: Is "Fuel Cell Feasibility Study," mentioned in your testimony, the same as market study? Is it available for public review? If so, please submit a copy for record.

Answer: The "Fuel Cell Feasibility Study" mentioned in our testimony refers to the Georgetown University Army Coal-gasification Fuel Cell Programs feasibility Study in process of final mark-up. Clins 0004, 0005 and 0006 represent the final economic, financial and executive summary tasks. The contract officers' final mark-up is expected within the next few weeks, and the executive summary (0006) shortly thereafter. A copy of the final mark-ups and executive summary will be submitted to the subcommittee for the record as soon as it is completed. At this time it is possible to summarize the results of the study.

The feasibility study undertook to evaluate the viability of a basic commercialization plan for coal gasification/fuel cells, by packaging four sites in the United States. A return on investment and return on equity for the private sector has been determined for each site based upon detailed preliminary engineering designs for each specific site. Two of the sites have potential commercial viability; two sites do not. The study does not recommend developing any of the sites at this time due to the drastic drop in oil prices. Commercialization is based upon a general 70-30 or 80-20 federal-private cost sharing for the first 11.5 MW fuel cells; 50-50 cost sharing for 2nd modules of 11.5 MW each; and a 0-100 federal-private cost sharing for the 3rd and follow-on modules, ending outyear federal funding. The thrust of this project is to set private risks on a scale balanced by descending levels of federal participation, with a basic market of 15-40 army sites that are set for gas/oil conversion to coal use and potentially fuel cell site specific applications. This formula could also be utilized for the 250 DOD installations needing coal conversion. The reason commercialization is not viable at this time is the falling price of oil which affects electric rates. Unless Congress mandates coal utilization as a national need, the drop in oil prices will prevent fuel cell commercialization at this time.

2) Question: Dr. Berger anticipates that within 3 years, the bus application would be possible. You are predicting a longer period. What is the difference between your projections?

Answer: Actually, our projections are similar. The same three year period is required to lay the groundwork for the commercialization process. According to the schedule we propose the initial test model will be completed at the end of 18 months; the second pre-production model will be completed on the 24th month; the third pre-production model is scheduled for completion on the 36th month. At this point the bus application will have been achieved, and the commercialization process of manufacturing 10 production buses in the next 12 months (the 4th year) on a decreasing fuel cell/ component cost curve will be able to begin.

3) Question: "Does your four-phase program, with a project cost of $9.5 million to $11 million over four years, cover the research cost at Los Alamos?"

Answer: Yes. It includes all necessary pre-commercial testing on phosphoric acid fuel cells, processors, motor controls and batteries.

4) Question: "What are the financial participations by private fuel cell and automotive companies?"

Answer: It is envisioned that the federal cost share decreases as the first test vehicles are completed, i.e. the first vehicle is about $750,000, the second and third are $500,000, with the ten bus production costs lowering, e.g. fuel cells dropping to $60,000 each in federal cost share, to reach a threshold of commercialization.

5) Question: "Would you or Dr. Berger comment on Dr. Ackerman's claim that only "monolithic" oxide fuel cells have the potential for efficient operation in vehicular application?"

Answer: Dr. Ackerman's comments are probably legitimate when one addresses long term development of very large vehicles of immense power requirements such as locomotives, ships and other large systems because that can convert the excessively high temperatures produced by the oxide fuel cells in bottoming cycle processes. We do not agree that smaller low-power requirement vehicles can safely or legitimately use the high temperatures of oxides, and certainly not if they are to be internationally competitive in the near term. The phosphoric acid fuel cells are the near-term units that should be utilized initially to push fuel cell commercialization forward.

The PEM (Proton Exchange Membrane) fuel cell is a next-generation technology that could be used to retrofit fuel cells. There would also be ongoing refinement, and competitive development of phosphoric acid types would continue. Our current joint effort with Los Alamos clearly indicates this path as the most practical and safe way toward near-term commercialization.

Clearly the high temperatures developed under the monolithic oxide fuel cells would require more expensive materials which would push the costs higher and therefore make commercialization more difficult.

APPENDIX II

Additional Material Submitted for the Record

Testimony of

William H. Podolny

Chairman

International Fuel Cells Corporation

Before the

Energy and Natural Resources Subcommittee
on Energy Research and Development

U.S. Senate

February 24, 1986

Mr. Chairman, I appreciate the opportunity to testify before your committee. As the Chairman of International Fuel Cells Corporation, I represent an entity which is an affiliate of United Technologies Corporation. This entity was incorporated in 1985 to fulfill a commitment to this committee, the Congress and the federal government. International Fuel Cells Corporation, IFC, has been organized and is operating with the sole objective of developing a commercial fuel cell power plant. The word "commercialization" is sometimes used freely and haphazardly in conversation and publications concerning the end point of research and development efforts. In the real world, however, such words require precise definition when considering the level of resources that must be placed at risk. It is not the purpose of this testimony to develop definitions and criterion for commercialization of fuel cell power plants. Suffice it to say, that before there can be a continuing business success; a manufacturer, offering competitive equipment on a continuing basis, must identify a customer willing to buy and use such equipment because it is beneficial to his business. There is, however, an intermediate step where either the manufacturer or the customer, or both, assume a nonprofitable risk position. During this exposure, there must be confirmation of the critical aspects of economic viability on both sides.

IFC investors have agreed to an initial product and market development investment as a demonstration of integrity of purpose for the world's first commercial configuration of an electric utility power plant. Investment is being made as a demonstration of purpose that permits IFC to go forward to the electric utility industry. IFC is soliciting sales commitments from electric utility companies for an initial lot of power plants. This will permit the evaluation of the product by the electric utility industry in such a way that a clear determination of future markets can be established. This will allow evaluation of the manufacturing process and the product to confirm the prospectus for achieving competitive first costs and competitive operation costs.

IFC has established a limit to the loss it could incur if the venture fails as its contribution towards the commercialization process. In our petition to the electric utility industry for sales commitments, we are assuming a certain degree of potential loss by the electric utility companies if the initial equipment fails to live up to expectations and promises. IFC's commitment to a potential loss is a demonstration of integrity designed to encourage the utilities to consider participation and potential exposure. The most critical element of the commercialization process is to provide the electric utility companies with confidence that their potential loss will be minimal and that their potential future benefits will be high.

IFC is dedicating all of its available resources at high risk to the specifics of the product and market development. The greatest single contribution that the federal government can make, as part of

its long time engagement in the evaluation and development of the technology, is to continue the support of technology improvements that could provide the basis for a successful evaluation and the basis for clearly meeting competitive initial and operating cost requirements in future deliveries.

Normally, it takes 15-20 years for the utility industry to accept the viability of a new generating technology. In the case of the fuel cell, the evaluation process must be accelerated to establish the economic and commercial viability of the fuel cell power plant before 1992-1993. It is during this time frame, that the electric utility industry will add substantial generating capacity. It is for that reason that despite our recognition of the need for budgetary restraint, we cannot agree with the Administration's position concerning the Department of Energy's recommendation to defer the FY 1986 appropriation and its budget request for FY 1987.

The private sector, which includes this manufacturer, individual electric utilities and gas utilities and their respective research institutions, have made major continuing investments in this technology area since 1965. The federal government has supported specific activities that this company and its predecessor have been responsible for since 1975. More dramatically, however, in the last 3 or 4 years as we gained momentum and improved the prospects for commercial viability, our program results have been truly impressive. As mentioned above, the creation of IFC is also a result of the successful program.

The federally supported programs, which also include private sector investments, led to the very successful results of the 4.5MW electric utility fuel cell power plant demonstration program in New York and Tokyo. All of the technical and operating features: power level, emissions, response rate, automatic operation, short lead time, environmental site acceptance, noise, etc., were established with little or no discount from the objectives. Specifically, the demonstration plant operated for almost 3,000 hours and generated 5.4 million kilowatt hours of power. The concurrent improvement in the various technologies to achieve superior performance, cost, durability, and reliability in full scale componentry, together with advanced systems concepts, provided the foundation to undertake the IFC product venture risk.

Simultaneously, the gas industry has pursued a federal and privately funded program to establish the operational viability of the on-site fuel cell power plant based on the comprehensive field test using a 40KW experimental fuel cell power plant. This program was an outstanding demonstration of advanced technologies, research and development. More than 40 power plants in the hands of some 35 utility companies together with a handful of Dept. of Defense and industrial installations achieved on the order of 270,000 hours of operation to date with the relatively extraordinary gross average availability of 65-67%.

Electrical efficiency, energy efficiency, isolated load following operation, grid-connect operation, co-generation, computer reliability, power demonstrations, parallel operation with multiple units and extremes in climate and physical location were all part of the test and all successfully demonstrated. A parallel program to establish advanced systems, improve performance, lower costs, strengthen reliability, increase durability and endurance by research and development in advanced technologies were so successful that it has established a basis for IFC to announce, together with the gas utility industry, its plans to go forward with a second commercial fuel cell product venture, i.e., a 200 KW on-site fuel cell power plant with initial delivery starting in mid 1990. That product venture will differ somewhat from the electric utility product venture in that the investment in the product development will depend upon obtaining a significant number of initial commitments from the gas utility customers.

In addition, there have been advances in molten carbonate technology and there have been identified advances in phosphoric acid technology which establish a stronger basis for fuel cell power plants becoming amenable to operation on gasified coal, whether integrated or not. Efforts to improve componentry and system elements to make such fuel economically viable for fuel cell power plants for a bona fide technology program are deserving of support.

IFC recommends the following levels of funding for specific IFC programs in Fiscal Year 1987:

1) 11 MW, water-cooled, phosphoric acid technology development program - $7 million;

2) on-site technology development program - $3 million;

3) molton carbonate technology development (complete technology development initiated by FY 1986 funds and initiate full height stack demonstration program) - $4 million; and

4) solid oxide (money to initiate a planer solid oxide cell configuration) - $1 million.

###

IGT
Headquarters

Bernard S. Lee, President
312/567-3741

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February 18, 1986

The Honorable James McClure
Senate Energy & Natural Resources Committee
SD-358 Dirksen Senate Office Building
Washington, DC 20510

Dear Senator McClure:

I would like to request that this letter be entered as part of your record for the Fuel Cell Hearing you are holding on February 24, 1986.

IGT, a not-for-profit, non-nuclear, energy technology research and development organization, has been involved in fuel cell research since 1958.

During the early years, three types of fuel cells were Under development: phosphoric acid, molten carbonate, and solid oxide. Between 1963 and 1971, the IGT research and development effort concentrated on both the phosphoric acid and the molten carbonate fuel cell. However, since 1971, IGT has emphasized work on the molten carbonate fuel cell because we believe the molten carbonate fuel cell is best suited to meet the goals of both the electric industry and the requirements of industrial cogeneration. Cogeneration will result in energy savings, whether the cogeneration method is a molten carbonate fuel cell plant or a more conventional device. But, the inherent high efficiency of the molten carbonate fuel cell yields savings not offered by conventional cogeneration plants.

While all three types of fuel cells can address the cogeneration market, the molten carbonate fuel cell has a greater efficiency than either the phosphoric acid or solid oxide fuel cell and provides hotter waste heat than phosphoric acid.

FUEL CELL TECHNOLOGIES

Type	Technology Status	Efficiency*	Waste Heat
PAFC	Commercial	40%	Low Temp
MCFC	Advanced R&D Pre-Prototype	50%**	>600°F
SOFC	R&D	45%**	>600°F

* Fuel to ac power
** Conventional system

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Illinois Institute of Technology

In addition, the molten carbonate fuel cell can utilize natural gas directly as a fuel and can also operate at elevated pressures. These capabilities, when developed, can increase the efficiency to 60% for the molten carbonate system.

As R&D continued at IGT on molten carbonate fuel cell development, we made great improvements in cell life and performance which led us very naturally into investigation of other applications. For example, one of the most promising technologies for coal use is the combination of a coal gasifier with a molten carbonate fuel cell for the generation of electrical power. Molten carbonate fuel cells could see a variety of uses, both in natural gas utilization and electricity production, as well as industrial applications of cogeneration.

In other work at IGT, we have made a careful study of gas cleanup systems to remove contaminants, such as chlorine and sulfur, in the fuel used by the molten carbonate fuel cell. We have made significant strides toward eliminating or lessening thepresence of these contaminants. Current and planned research and development in hot gas cleanup systems indicate that reasonable levels of contaminants can be maintained. However, while we believe this "front end" contaminant research should continue, pollutants could still appear in the feed gas which would cause degradation and poisoning of a conventional fuel cell.

It would be desirable for a molten carbonate fuel cell to have a tolerance to reasonable levels of contaminants, thus reducing the cost and complexity of gas cleanup and permitting the system to survive process upsets which would cause unacceptable levels of contaminants to reach the fuel cell.

In order to achieve this goal, IGT is working under a DOE contract to develop a contaminant-resistant molten carbonate fuel cell.

The optimum coal gasifier/molten carbonate fuel cell combination will minimize cleanup of the coal gas, maximize contaminant resistance of the fuel cell, and will withstand unexpected gasifier upsets without permanent damage to the cell.

Congress has shown an appreciation of the need for fuel cell research even during the recent lean budget years. We would encourage a continuation of this support in light of the tremendous energy savings to be gained through fuel cell industrial cogeneration and the economic benefits offered by expanded efficient, environmentally safe uses for coal.

Sincerely yours,